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December 20 – 21, 1965

Metallurgy :
Iron and Steel
Non-ferrous Metals

WORKING GROUP 7

COUNCIL OF SCIENTIFIC & INDUSTRIAL RESEARCH, NEW DELHI

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NEW DELHI

Printed at Delhi Printers, 21 Daryaganj, Delhi 6

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Strategic Non-ferrous Minerals and Metals

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The present emergency has brought to the forefront the problem of meeting the requirements of strategic defence and other high priority industries of important metals based on indigenous resources. It needs little emphasis to state in the present context that high priority should be given to the exploration of suitable ore resources, immediate follow-up action in the development of already proved reserves and establishment of production units (even on pilot scale where necessary) so that our requirements are met partially if not wholly at an early date.

The metals that need heavy usage today are aluminium, copper and zinc. These metals are needed in large quantities and considerable progress has been made in the production and planning of production capacity for aluminium ; however the projected copper and zinc production has not materialized so far and it is imperative that recognizing the present chronic shortage of foreign exchange, urgent steps are taken to (i) procure concentrates of zinc from abroad, (ii) produce concentrates from our own resources in Rajasthan, and (iii) get the projected plants of copper and zinc at Zawar, Khetri, Vishakhapatnam and Kerala established in the near future.

In addition to copper and zinc it is imperative that secondary refining capacity of non-ferrous metals in short supply should be set up. Throughout the country public opinion should be created to part with old and redundant utensils of brass and bronze available in millions of households, which could then be remelted and utilized for various important defence and strategic uses.

Regarding utilization of all sources of scarce metals such as copper and zinc etc. apart from secondary refining, the huge quantities of zinc from dross generated during galvanizing have also to be reclaimed. In this connection, it may be mentioned that the National Metallurgical Laboratory (NML) has developed a process for the distillation of zinc from the galvanizers' dross and based on these investigations, the Indian Tube Co. and TISCO are shortly to put up dross distillation plants thus enabling recovery of large quantities of zinc.

In view of continued scarcity and known inadequate resources of various metals like copper, zinc, nickel, tin, tungsten, molybdenum, cobalt etc. the NML has been endeavouring through its research and development programme to explore the possibility of substitution of these metals partially or where feasible wholly with such metals as are available from

indigenous resources, e.g. aluminium, manganese, chromium etc. in various applications. A comprehensive report on the subject covering wide range of applications in ferrous and non-ferrous metals and alloys where indigenous substitute metals and alloys can be used was submitted to the Metals Committee of the CSIR by Dr B. R. Nijhawan and Shri K. N. P. Rao in June 1963.

In order to focus further attention on this vital subject the NML is holding a symposium in March 1966, where all the aspects of substitute alloys will be discussed in respect to others offering potential scope for research and development.

The one non-ferrous metal whose resources are abundant in India is aluminium ; on account of the versatile properties possessed by aluminium, it has already found multiple end-uses, and new uses are fast developing in the face of acute competition with other alternative materials. Thus, aluminium foils are good substitute for lead, tin, paper and plastics. Aluminium electrical conductors are fast replacing copper particularly in India. The long-term supply of aluminium in India is particularly favourable in comparison with other Indian non-ferrous metals due to abundance of high grade ores and establishment of modern aluminium production units in India. Based on the long-term supply position and technical considerations of fabrication, aluminium conductors should continue to be appreciably cheaper than copper conductors for the same capacity. Considering the technical aspects of material usage, it appears that the working, jointing, installation and maintenance costs of aluminium conductors and equipment should be no higher than those incurred in carrying out similar operations on copper, lead etc. Indeed, the lower weight of aluminium should result in reduction in some of these costs, such as transportation and erection. Aluminium can replace lead for cable sheathing with economy in the first cost and economy in maintenance. A certain degree of substitution of copper by aluminium has already been accomplished during the Third Five-Year Plan, such as replacement of bare copper conductors by aluminium conductors to the extent of 5,000 tons and 15,000 tons by 1965–66 and 1970 respectively ; substitution of 1,000 miles of paper-insulated cable based copper wire by aluminium wire in 1965 and 2,500 miles in 1970 ; substitution of copper by aluminium in heavier VIR and PVC wires to the extent of 200 million yards by 1965 and 600 million yards by 1970 ; replacement of copper and copper base alloys by aluminium and other alloys for switch-gears etc., by about 10 per cent and 20 per cent in 1965 and 1970 respectively. Similarly, in the field of zinc, the big gap between indigenous production and consumption warrants immediate consideration of substitution of galvanizing by aluminizing for all potential applications in India. Other applications in which aluminium can easily substitute copper, zinc or lead include electrical industry, cables, motors, generators, transformers, condensers, conduit pipe etc., coinage, lithographic plates, paints, hardware brass and bronze fittings etc.

Zinc consumption in India during 1960–61 was about 70,000 tons, which represented a 100 per cent increase over the previous five years. The estimated annual requirements of zinc by the end of 1965 are about 185,000 tons which again represent more than 100 per cent increase over the present five-year period. Even with the setting up of the proposed plants at Udaipur, Alwaye and Vishakhapatnam, the smelting capacity of zinc in India would be far short of our increasing requirements. The big

gap in indigenous capacity and requirements of zinc warrants an immediate consideration of replacing galvanizing by aluminizing since galvanizing industry in India consumes the major bulk of imported zinc.

The above criteria apply with equal emphasis to alloy, tool, special and stainless steel industry in this country and the need to formulate and develop families of indigenous substitute alloy compositions is all the more necessary and urgent, eliminating or minimizing as far as possible alloying elements, such as, nickel, molybdenum, tungsten, cobalt etc., the resources of which are practically nil in this country.

The NML has right from its inception, embarked upon some major research and development themes on substitute alloys and alloy steels, such as the nickel free austenitic stainless steels, low alloy high tensile structural steels, indigenous tool and die steels, iron-aluminium alloys, nickel and cobalt free electrical resistance alloys, nickel free coinage alloys, manganese bearing substitute brasses, aluminizing of steel, aluminium-based substitute alloys for the production of diverse ranges of end products to exacting specifications and practical needs.

There are other metals which though needed in smaller quantities, and with lesser indigenous resources are of strategic importance, such as tungsten, lead, cadmium, antimony, nickel, molybdenum, magnesium, titanium, calcium, barium, strontium, germanium, selenium, beryllium etc. Resources and uses of some of these important metals are as follows.

Nickel

Nickel is present in the copper and uranium bearing minerals in Singhbhum district, Bihar. The copper ore of Singhbhum contains 0.8 per cent nickel and the copper ingots produced by Indian Copper Corporation contain 0.26 per cent of nickel. Some pockets of nickel sources are reported in Reasi, Ramsu, Buniyar, Khaleni in Kashmir and Manipur in Assam. It is expected, that 400 tonnes can be recovered as a by-product during electrolytic refining of copper at the Indian Copper Corporation Ltd, who are engaged in setting up an electrolytic copper refining plant at Ghatsila. The recovery of nickel from slag should also be studied as an additional source for nickel. In addition, the possibility of recovery of nickel from the Jaduguda Uranium Project should be explored. Recovery of nickel from the considerable deposits of nickeliferous laterites occurring at Keonjhar and Mayurbhanj (Orissa) can also be studied and steps to send the ore samples to the NML for these studies should be taken at an early date. The deposits of Manipur (Assam) in view of their distant location are considered unsuitable for immediate development. Beneficiation studies were undertaken at the NML on a low grade nickeliferous ore from Moreh area deposits in Assam. The sample as received assayed (per cent) Ni 0.48, Fe 8.94, SiO_2 37, Al_2O_3 2, CaO 0.04, MgO 32.83, Co 0.05, and S 0.146. The nickel content was found to be almost uniformly distributed in the mineral in fine grains and could not be beneficiated with normal ore dressing methods.

Nickel is used in the making of alloy steels, stainless steels, high temperature electrical resistant alloys, copper-nickel, nickel-silver alloys, cast irons, nickel base alloys (inconel, Monel etc.) and in nickel plating industry. With the development of alloy steel industry during the Fourth Plan Period the demand of nickel will increase considerably.

Manganese

India is a major producer and exporter of manganese ore in the world. The total reserves of manganese ore are estimated at 100 million tonnes of which 85 million tonnes are in Madhya Pradesh and Maharashtra. The other deposits are in Srikakulam district, Andhra Pradesh; Manbhum district, Bihar; Panch-Mahals, Baroda district, Gujarat; Banswara and Udaipur districts in Rajasthan and Midnapur district in West Bengal.

With a view to utilize low-grade manganese ores hitherto dumped in huge quantities on the mine sites, the NML has conducted exhaustive studies on the beneficiation of low-grade manganese ores.

Manganese is used as a ferroalloy in the production of steel for deoxidation and alloying purposes. The main ferro-alloys of manganese are ferro-manganese, silico-manganese and spiegel eisen. There are several plants producing standard grade (high-carbon) ferro-manganese in the country; however, commercial scale production of low-carbon and medium carbon ferro-manganese has yet to be established. Manganese metal and ferro-alloys are also required in the production of stainless steel, Hadfield and other alloy steels, steel mill rolls, grey and malleable castings, while manganese dioxide is widely used in the dry battery industry. Although India produces ferro-manganese for internal consumption and export purposes, manganese metal of high purity is not produced in the country. The NML has developed an ingenious process for the production of electrolytic manganese and manganese dioxide. The process has been leased to Messrs Devi Dayal in Bombay for commercial scale production to meet the home and export requirements of high purity electrolytic manganese and manganese dioxide.

Chromite and ferro-chrome

There are sizable chromite deposits in India in Singhbhum (Bihar), Mysore, Ratnagiri and Sawantwadi (Maharashtra), Krishna district (Andhra Pradesh) and Salem (Madras). Reserves of all grades of chromite are estimated at about 4.9 million tonnes which may be considered adequate for indigenous requirements.

Chromium is recovered from chromite for producing chromium and ferroalloys for making chromium bearing multitude alloy steels and high chromium special alloys. Other major uses of chromite are in the production of steel plant refractories, in chemical industry etc. It is only recently that export of high grade chromite ore has been stopped by the Government of India.

Exhaustive studies on ore-dressing and thermal beneficiation of low-grade chrome ores for their utilization have been conducted at the NML. Ferro-chromium is so far not manufactured in India. The NML has developed the technical know-how for production of high-carbon and carbon-free ferro-chrome and has from time to time met the requirements of defence and other industries of various grades of ferro-chrome.

Tungsten

Tungsten is used as ferro-tungsten in making high speed and other alloy and tool steels, production of cemented carbides, cutting and wear resistant alloys, alloy welding rods, electrical contact alloys and resistant alloys. Recent uses as pure metal include wire, rod, sheet and various

shaped parts produced by powder metallurgy techniques. In India, we have small pockets of Wolframite in Degana (Rajasthan) and Bankura in West Bengal, but so far the concentrates produced have been of nominal value.

It is imperative that mining of Wolframite is urgently taken up in Rajasthan and production increased by the Gauripur Industries Ltd, who have a lease of Bankura deposits in order to produce sizable amount of concentrates for production of tungsten and ferro-tungsten.

Lead

Lead occurs in Bihar, Orissa, Andhra Pradesh, Rajasthan, Madras, Uttar Pradesh and Jammu and Kashmir. Details of the reserves in many locations are yet to be assessed and early steps should be taken to examine the possible availability of ore for concentrates. The ore reserves at Mochia Magra (Rajasthan) down to a depth of 1,000 ft have been estimated as between 8 and 10 million tonnes of proved and probable ore. The grade of ore is nearly 7 per cent metal content of both lead and zinc. The lead concentrates produced are smelted at Tundoo in Bihar for extraction of lead and silver.

Lead is used mainly for making plates for electrical storage batteries and for lead sheathed cables. Large quantities are also used in buildings for water pipes etc. Metallic lead is used as an alloying element in anti-friction, babitt and white-metal alloys, die castings, type metal, solder and other bearing alloys. In the chemical industry lead is used for manufacture of pigments like white lead and red lead, lead sulphate, lead chromate, lead dioxide etc.

In view of lead production of about 4,000–5,000 tonnes per year only and requirements per annum amounting to over 65,000 tonnes, it is imperative that all the resources at various locations be brought under immediate production of lead-zinc ores and the lead concentrates sent to Tundoo for increasing production. The private lessees should be asked to increase the production during the emergency and necessary help to intending parties should be given by the government by leasing out new locations for immediate production of ore concentrates with arrangement for collection of ore concentrate for sending on to Tundoo plant for smelting.

Antimony

The antimony smelting capacity of the only firm at Bombay is 1,000 tonnes and is solely based on the import of antimony ore concentrates. Reserves of commercial significance are reported at Bara Shigri (Lahaul, Punjab). It is expected that 24 tonnes of the ore containing an average 45 per cent antimony will be obtained per foot of depth from this source. Small occurrences are also reported at Chitaldrug, Bellary (Mysore), Hazaribagh (Bihar), Cuddapah (Andhra Pradesh), Kolari area in Nagpur and Pokhri area in Chamoli district, Uttar Pradesh.

There has been some progress made in the production of antimony in India during the last few years due to increased demands for making special alloys. The metal is required in the manufacturing of ball bearings and batteries and concentrates have been imported from Iran, Turkey and Peru. The availability of soda ash, furnace oil and iron scrap has helped the only refinery in India to raise its antimony output. The

demand of antimony is expected to increase beyond 1,000 tonnes per year which represents the present capacity of the Plant. The known deposits should be worked during the emergency to produce concentrate within the country.

Cadmium

There is at present no production of cadmium metal in India; it is, however, estimated that about 80 tonnes of cadmium will be recovered during the electrolytic refining of zinc when the Electrolytic Zinc Smelter of the Metal Corporation of India (now taken over by the Government of India) at Udaipur goes into full production.

Similarly, cadmium recovery should also be undertaken at the projected zinc plants at Alwaye and Vishakapatnam. A major use of cadmium is in the electroplating industry for providing protective coatings, household appliances, industrial machines, radio and television sets, electrical and electronic equipment, hardware, fittings, instruments and fastening items such as nuts, bolts, screws, rivets, rails etc. Cadmium is particularly adaptable to electroplating of complicated and intricate shapes because it can be deposited more uniformly in recesses. Other applications include cadmium-silver type solders and cadmium alloyed with copper for telephone wires. One of the major uses of cadmium is in the pigment and chemicals industry. Nickel-cadmium batteries give longer life than lead-acid batteries.

Molybdenum

Molybdenum as a major alloying element is used in the form of ferro-alloy for production of alloy steels, stainless steels, high speed steels, hot-working steels, steel mill rolls and in grey and malleable iron castings. There are no known major resources of molybdenum in the country. Possibility of recovery of molybdenum from Jaduguda project of the Atomic Energy Department should be looked into. Resources of molybdenum at Mangamali in Kanyakumari district and in Medale and Karimanagar districts of Andhra Pradesh are shortly to be taken up for assessment by Geological Survey of India. Our requirements of molybdenum are met by imports only. The metal has also recently found use as pure metal in high temperature applications in the form of wire, sheet, rod etc., and as powder.

Vanadium

Extensive deposits of vanadium bearing titaniferous magnetite containing 0·9–1·4 per cent vanadium have been reported in Singhbhum district of Bihar and Mayurbhanj district of Orissa. The ores are not suitable for direct production of ferrc-vanadium and have to be chemically treated for recovery of vanadium pentoxide. The reserves of these ores are estimated at about 20–22 million tonnes. The NML has developed a process and comprehensive technical know-how for production of vanadium pentoxide from these deposits. The major use of vanadium is as addition element to various alloy steels as ferro-vanadium.

Titanium and rare earth metals

Extensive deposits of ilmenite are found in India in the beach sands of Kerala, Ramanathapuram, Tanjore, Bimlipatam and Ganjam

coast tract; Maharashtra coast from Purangadh to Mulgund has also good deposits of ilmenite sands over a distance of about 41·48 km. Extensive deposits of titaniferrous magnetite are also found in Dhalbhum sub-division of Singhbhum, Bihar. Travancore (Kerala) beach sands extending from Quilon to Cape Comorin are the richest deposits; besides ilmenite, the beach sands contain rutile, zircon, garnet, monazite and sillimanite. The reserves of ilmenite in the beach sands of Travancore have been estimated at 365 million tonnes. Rutile also occurs in Narnaul in Punjab, Rajasthan, in the mica schist of Singhbhum and in the Kyanite rocks of Dhalbhum Mayurbhanj.

Most of the ilmenite is consumed in the manufacture of pigments, some is used in making welding rod flux coatings. Other uses are for production of titanium metal and Ti-base alloys, ferro-titanium, carbides and ceramics, fibre glass and chemicals.

Titanium metal

It is used in supersonic aircrafts, in firewalls, skin, landing gear components, hydraulic tubing, shrouds, oil and fuel tanks, engine support etc. Extensive use of titanium is made in jet engines and space craft and in the chemical industry in reaction vessels, pumps, heat exchangers and heating coils etc. and in the surgical implements.

Systematic studies were undertaken at the NML for the production of different grades of ferro-titanium and the process is available for release to the industry. The alloy containing 25–30 per cent titanium is produced by the reduction of ilmenite in presence of energizers. The reduction of FeO and Fe_2O_3 from ilmenite increases the exothermic character of the process. The heat liberated is, however, still not sufficient for the normal run of the process and energizers have to be used. The slags may be made more fluid by using fluxes. High grades of ferro-titanium containing 35–40 per cent titanium are produced by using rutile instead of ilmenite.

The production of ferro-alloys by alumino-thermic reactions is a closely guarded secret and is rather new to Indian ferro-alloy industry. There has been no regular production of any of the ferro-alloys by alumino-thermic reactions excepting the production at the NML to meet the immediate demands of some essential industries. The country's annual requirement of carbon-free ferro-titanium may not exceed 200 tonnes when the alloy and steel production is established in the country. The demand is expected to increase with the expansion of alloy tool, special and stainless steel plants and the production of ferro-titanium should be undertaken in the country.

The importance of titanium metal and its alloys in modern jet aircraft manufacture and chemical industry should give an impetus to the utilization of our considerable resources for setting up a pilot plant for its production initially to meet immediate requirements of these industries. The NML has already done some work on titanium production by Kroll's process and in case a pilot plant is set up can train up Indian scientists and technicians which at a later date may assist in the commercial scale production plant.

Zircon

The ore of metal zirconium occurs in the beach sands of Travancore, mixed with monazite, ilmenite and rutile. It constitutes 6 per cent of the sand and is recovered as a by-product in the tailings after separation

of monazite and ilmenite. India is one of the important zircon producing countries. The NML has developed a process for obtaining zirconium dioxide from zircon.

The metal zirconium has also assumed strategic atomic importance and has wide application in nuclear reactors. It is also used in surgical gadgets. Its superior mechanical properties and corrosion resistance even at very high temperatures coupled with low neutron absorption cross-section make it ideal for use as a constructional material for high temperature thermal reactors. In the form of silicon-zirconium and ferro-silicon-zirconium, it is used as an alloy addition for making special alloys including specialized form of deoxidation and scavenging of steels. It is used as a grain refiner for magnesium base alloys; it improves high temperature properties of beryllium-copper alloys. Nickel alloys with 2-10 per cent zirconium are used for cutlery purposes and 25–30 per cent zirconium addition in nickel gives high speed cutting properties to the tool. Zirconium silicate and zirconium dioxide are found useful refractory materials used for the lining of electric furnaces and burning chambers in glass industry, for foundry work and electrical insulators.

Rare earth metals are widely used as alloying additions, e.g. to aluminium and magnesium base alloys, and as purifying and refining agents in ferrous and non-ferrous alloys. Usually rare earths are added in the form of a mixture. Ore is Lan-Ceramp (lanthanum, cerium) with an average analysis: Lanthanum 30%, Cerium 45–50% Mixture of Neodymium, Praseodymium, Samarium and Iron 10% max.

The other mixture is 'misch metal' derived from monazite containing 22–25 per cent lanthanum, 50–55 per cent cerium, 15–17 per cent neodymium, 8–10 per cent other rare earth metals (varying according to origin of monazite).

Extraction of the rare-earth minerals despite their abundant resources, is highly complex and costly. With the improvement of extraction techniques, the cost may, however, come down in course of time.

Beryl

In India, beryl is found in Ajmer-Merwara (Rajasthan). It is also found in the mica mines of Hazaribagh and Nellore districts. The mica deposits of Udaipur also yield certain quantity of beryl. India was at one time, the only source of beryl supply.

Beryllium is specifically used as a moderator in nuclear reactors. It is also used in special applications in aircraft missiles, space vehicles and research and developments in this field. Heat treatable beryllium-copper alloys are outstanding for their high strength and high thermal and electrical conductivity, beryllium-nickel alloys are also used as heat-treatable high-strength alloys. Beryllium is also alloyed with light metals to improve their processing and properties. India imported 595 lb. of beryllium metal and alloys (except Be-copper) in crude form and scrap during 1962. USA imported 885 and 150 short tons of beryl from India during 1961 and 1962 respectively.

Selenium

Selenium is used in industry to produce (i) dry plate electrical rectifiers, (ii) xerographic plates, (iii) photo-cells, (iv) solar batteries, (v) television

cameras, (vi) glass and ceramic industry, (vii) pigment industry, (viii) steel industry, and (ix) chemical industry etc.

It is occasionally found in conjunction with native sulphur and in the form of selenides of other metals in minerals such as Clausthalite PbSe, Crookerite CuAgSe, etc. and most frequently it is found as an accessory mineral in base metal ores of Pb, Cu and Ni. Selenium is recovered normally as a by-product in the manufacture of these metals, and in India can be recovered from the copper slimes produced at Ghatsila.

Germanium

Germanium is a well-known semiconductor metal and is extensively used in the electronics industry. It is used as a crystal diode rectifier, triodes and as transistors. Germanium power rectifiers are also in commercial use and have many advantages over other types. Germanium is transparent to infrared light waves. This property is utilized in the infrared spectroscopes and other optical instruments. Special germanium devices are used in extremely sensitive infrared detectors supplementing radar for detector purposes. Magnesium germanate is used as a phosphor in fluorescent lamps. A germanium resistant thermometer has been developed recently which will operate at temperatures near absolute zero.

Devices employing germanium have led to miniaturization and improvements in radios, computers, hearing aids and other communication equipment. Replacement of vacuum tubes by transistors has allowed direct long distance telephones. Military and defence equipment has been vastly improved and miniaturized.

Germanium is found in minerals like Argyrodite, Canfieldite, and Germanite. It also occurs in some lead-zinc and copper-lead-zinc ores. It is also present in some coals and is recovered from coal ashes and flue dusts.

It is reported that the ash of some coals from Assam and Hyderabad coal fields contains recoverable quantities of germanium metal. Similarly, coal ash and flue dust from various power stations can be utilized for the recovery of germanium. Therefore it is vital that research and development is undertaken on the recovery of germanium from various coals in our country. Steps in this direction are being taken at the NML.

Graphite

Graphite occurs in Mysore, Andhra Pradesh and Orissa and to some extent in Kerala. There are a few working mines; however in 1964 over 2,000 tonnes of graphite was imported from abroad. It is necessary therefore that the production from the working mines be increased. Sambalpur and Kerala reserves should be explored and the possibility of working of these deposits assessed for necessary utilization. Graphite is mainly used for manufacture of crucibles, retorts, muffles and refractories. Graphite crucibles using indigenous resources have been developed at the NML and the process has already been released to a party who have gone into production.

Phosphorus and superphosphate

The production of phosphorus needs particular attention and based on indigenous resources the firm licensed to produce phosphorus (M/s Star Chemical Ltd, Bombay) should expedite production.

Apatite is mainly found in Singhbhum, Bihar and Andhra Pradesh and Tiruchirapalli (Madras). Beneficiation work was done at the NML on a low grade phosphate rock sample received from M/s Dhalbhum Phosphate Co. Ltd, Calcutta, and collected from Samaydih village in Singhbhum district Bihar, where the proved reserves are estimated at 6 million tonnes. For the production of superphosphate the phosphate rock should have a minimum guaranteed content of $Ca_3P_2O_8$ (called BPL in the trade) with maximum limits usually specified for oxides of iron and aluminium and for calcium carbonate. Commercial rock which is marketed does not fall below 66 per cent BPL, but most of it contains 70–80 per cent BPL. Usually, buyers specify a limit of 3 per cent total oxides, but as low as 0·5 per cent may be specified in some cases. About 2 to 4·5 per cent of $CaCO_3$ is not considered harmful whilst a relatively high fluorine content in the rock is sometimes objectionable. Superphosphate manufacturers prefer raw phosphate delivered in a fairly fine condition and hence a flotation concentrate of fineness 80–95 per cent minus 100 mesh can be readily acceptable to them. The phosphate sample tested at the NML had a P_2O_5 content of 23·26 per cent [$Ca_3(PO_4)_2$=50·78], SiO_2 19·31, Fe 11·32, Al_2O_3 9·15, CaO 30, F 2·10 and Cl 0·24 per cent. The rougher apatite float assayed 41 per cent P_2O_5 with a recovery of 95·5 per cent P_2O_5 in it. The concentrate fulfils the grade and size requirements laid for its use in superphosphate manufacture.

Magnesium

Ample resources of magnesite and dolomite are available in India. The magnesite deposits are estimated at 118·7 million tonnes. In Almora district a reserve of 12·19 million tonnes have been estimated by the Indian Bureau of Mines (1960) averaging 40–46 per cent magnesia. The U.P. State Geology and Mining Directorate has estimated tentatively 14·7 million tonnes at Pungar valley and Lahore valley. Madras and Mysore are the other states with the remaining figure for reserves estimated earlier. The NML has conducted pilot plant scale trials for production of magnesite refractories from Almora and Salem magnesite samples.

Studies of small scale production of magnesium metal by silico-thermal reduction process at the NML have resulted in the formulation of the project for a semi-commercial scale plant for production of 250 tonnes/year of magnesium metal at Jamshedpur from indigenous raw materials with design and setting up of the plant in collaboration with Central Design and Engineering Unit of the CSIR and the NML with technical know-how from the NML process. Magnesium is used as a constituent of various Al-base light alloys as also Mg-base light alloys used in structural components of modern aircraft, tanks and other weapons, various light structures such as bridges etc. and the metal in powder form is used for various ordnance and incendiary purposes.

In view of the increasing requirements of the above minerals and metals in the country and with given resources it is to be emphasized that speedy efforts be made by the Geological Survey of India and the Bureau of Mines to prospect various areas where such minerals are indicated. The Government of India should with cooperation of state governments assist where necessary the private lessees of various reserves to produce the required quantity of ores and concentrates. Wherever any ores have to be tested for beneficiation etc. speedy action is required to get the samples sent to the NML for beneficiation and for any further studies for recovery of the metal under reference.

It may be emphasized here that the NML has been actively engaged over the past years in research and development work for the utilization of indigenous resources through beneficiation of low grade ores and at the same time formulating the technical know-how for production of primary metals and ferroalloys of the minerals described above. This sustained painstaking research and development work has resulted in the projected setting up of the plant for integrated ferroalloy production at Durgapur and a semi-commercial plant for manufacture of magnesium metal at Jamshedpur. In addition production of ferroalloys by alumino-thermic processes developed by NML has been taken up by certain private sector parties also.

The resources of technical equipment, research facilities and technical manpower at the NML are always available to the various government and private agencies and foremost to the defence authorities and we assure all concerned that given the requirements and raw materials the NML will not be found wanting in relentless effort to meet the demands within our limitations of equipment and manpower. The defence requirements of various strategic materials have been met by us from time to time and we shall do so in future giving the top priority necessary during the present emergency.

Self-sufficiency in Indigenous Metals and Alloys

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The importance of well-knit heavy iron and steel bases to feed the chain reaction growth of secondary and processing engineering industries, in turn forming the backbone of consumer industries catering to the requirements of diverse products essential in times both of war and peace, needs no emphasis especially at the present emergency. In a developing country such as ours, the difficulties for striving towards self-sufficiency in iron and steel and other metallurgical and engineering industries are many but not unsurmountable. No country in the world is self-sufficient in her mineral requirements and India is no exception to the general law of nature. India's position as regards her resources of minerals (Table 1) for the production of metals of strategic importance may be considered satisfactory except those for non-ferrous metals. The Indian iron ores are rich in iron content besides being abundant. In the resources of manganese, India can claim the position as second largest producer. Resources in respect of aluminium, magnesite and ilmenite are significant. Copper, lead, zinc ores are highly deficient and deposits of metals such as nickel, tin, molybdenum, tungsten ores are practically absent or perhaps found in isolated uneconomical pockets.

With depleting mineral reserves and their shortages and in certain cases the almost total absence of some, researches and applied technological efforts are being continuously directed towards mineral conservation on the one hand and making the optimum use of available resources on the other. The resources of the country in which nature has been so generous to us, have to be fully exploited to national advantage and the existing production is to be stepped up and also non-conventional uses have to be made of different metals and alloys by developing suitable substitutes. These would call for planned research and ingenuity of high order, especially the promotion of indigenous skill and research technology in preference to the wholesale import of technology at all times and for all times. Mr Max Millikan, Director of the Massachussets Institute of Technology's Centre for International Studies, referred to the extensive difficulties of exporting 'Technology' before the United States Foreign Relations Committee; in his own words, "the advanced as also the developing nations have learned, over a decade of developmental efforts that the transfer and export of technology was very much more difficult and complex than was initially supposed". Under our own conditions, the traditional skill and talent of an Indian technician, engineer, or a scientist need to be fostered, if not protected and certainly not overwhelmed and engulfed by the wholesale influx of imported technology along with the mass of imported equipment and machinery.

Table 1—Mineral resources of India

Raw materials	Estimated reserves (million tonnes)	Grade available	Desirable grade
Iron ore	21,300	35 to 68% Fe	60% Fe and above
Manganese ore	over 100	26 to 52% Mn	56 to 48% Mn with 7:1 Mn/Fe ratio
Chromite	3.4	30 to 48% Cr_2O_3	46% Cr_2O_3 with 3:1 Cr/Fe ratio
Ilmenite	Reserves not fully assessed (Beach sands reserves are estimated over 350 million tonnes)	17 to 60% TiO_2	50% and above TiO_2
Coal	32,000	50 to 13% ash	Specifications vary according to the use
Limestone	Reserves not fully assessed, but amount to several thousand million tonnes	30% CaO and above	40% CaO and above according to the use
Graphite	Reserves not fully assessed	From 2% fixed C to 70 to 80% fixed C	30 to 85% F.C. according to the use
Gypsum	476.4	60% $CaSO_4$ and over	Over 80% purity depending upon the use
Lead and Zinc	8.5	1.5% Pb; 3.6% Zn	Over 7% Pb and over 55% Zn respectively
Copper ore	33.17	0.8 to 2.5% Cu	26% Cu and above
Vanadium ore	22.4	0.55 to 8% V_2O_5	80 to 85% V_2O_5
Fluorspar	Reserves not fully assessed Known reserves amount 1.76 m. tonnes	20% CaF_2 and above	85% CaF_2 (minimum) for metallurgical and 97% CaF_2 (minimum) for chemical industries
Tungsten	Reserves not fully known	Above 65% WO_3	60 to 65% WO_3

Iron and steel industry

The problems of iron and steel industry centre mainly round the raw materials, their characteristics, production technology, skill of operational personnel, utilization of the plant's full capacity, mechanical maintenance etc. The basic raw materials for iron and steel industry are iron ore, fluxes, steel scrap etc. The Indian iron ores, estimated at over 21,000 million tonnes, are termed 'classically' rich, their iron contents being 35 to 68 per cent. However, the indigenous ores are associated with high alumina in relation to silica which greatly hampers the handling operation in monsoon due to the blinding of screens and also affects smelting operations, particularly in relation to minimum fuel ratio and maximum productivity in quality. It has been estimated that for every one per cent decrease in the alumina content of the ore, the coke rate and flux rate would decrease by 85 and 136 lb. respectively per ton of pig iron made. The increase in production of pig iron would be about 2.5 per cent. The

overall saving per ton of pig iron produced would be Rs 4.00. Doubts held earlier in certain quarters on the inescapability of these ore treatment measures have been dispelled. It has been conclusively established that ore beneficiation is indispensable on metallurgical and economic desiderata.

The Indian iron ores were hitherto being produced by selective hand mining and in view of large scale production due to increased internal consumption in the iron and steel industry and for export purposes, it has become necessary to switch over to mechanized mining. The chrome, manganese and other important metallic ores are still being mined by selective hand mining. Proper conservation of mineral wealth requires that selective mining of rich ores should be replaced by economic upgrading of poorer grades and effective utilization of both. With the development of new mineral dressing techniques, the low grade ore deposits which were considered poor and could not be mined economically at all, have now become very paying propositions. It is possible to extract or upgrade valuable mineralogical constituents present even in minor quantities at much lower cost due to technological advances.

The present production of iron and steel is shown in Table 2. The requirements of steel in India by 1965–66 and 1970–71 are furnished in Table 3, and of alloy and special steels in Table 4. The imports of various types of steel during 1962–63 and 1963–64 are given in Tables 5 and 6. From a perusal of the imports, it can be seen that the import bill amounts to about Rs 73 crores in 1963–64 which is expected to increase as India would continue to import her steel requirements for some time to come, in view of the envisaged growth of engineering and allied industries, despite envisaged target of 16.5 million tonnes of steel production by the end of 1970–71. The Hindustan Steel Ltd, is expected to take a major share of steel production of about 9 million tons to be achieved by expanding Bhilai, Durgapur and Rourkela Plants and the Tata Iron & Steel Co. Ltd, and the Indian Iron & Steel Co. Ltd are likely to be expanded to supply about 4–5 million tonnes. As regards ferro-alloys, there is no commercial scale production excepting ferro-manganese and ferro-silicon and all other ferro-alloys needed are being met by imports. The demand of ferro-alloys may be gauged from their requirements for the alloy steel plant in the public sector designed for a production capacity of 80,000 tons of alloy steels a year as given in Table 7 which also indicates the demand of ferro-alloys for the production of 200,000 tons of alloy, tool, special and stainless steels per year. The ferro-alloy requirements to meet the ultimate requirement of 0.5 million tons a year of alloy, tool, special and stainless steels at the end of Fourth Plan will have to be imported entailing tremendous drain on the foreign exchange expenditure of the order of Rs 30 crores.

Table 2 — Production of pig iron, steel ingots and finished steel

(thousand tonnes)

	1960-61	1961-62	1962-63	1963-64
Pig iron	4351	5087	6149	6533
Steel ingots	3428	4267	5395	5945
Finished steel	2342	2965	3814	4296

SOURCE : Statistics for Iron & Steel Industry in India 1964, HSL, Ranchi

Table 3 — Requirements of steel in India (categorywise)

(tonnes)

Category	1965-66 Domestic demand	1965-66 Export possibilities	1965-66 Total	1970-71 Domestic demand	1970-71 Export possibilities	1970-71 Total
NON-FLAT PRODUCTS						
Semis	478,600	—	478,600	907,600	10,000	917,600
Structurals	937,100	—	937,100	1,705,900	150,000	1,855,900
Rails and fish-plates	543,900	—	543,900	691,300	100,000	791,300
Sleepers	33,300	—	33,300	89,100	—	89,100
Wheels, tyres & axles	112,700	—	112,700	147,500	20,000	167,500
Bars and rods	1,558,700	20,200	1,578,700	2,761,600	600,000	3,361,600
Wires and wire products	—	—	—	670,400	120,000	790,400
Total for non-flat products	4,044,300	20,200	4,064,300	6,973,400	1,000,000	7,973,400
FLAT PRODUCTS						
Tinplates	261,800	—	261,800	474,400	50,000	524,400
Sheets	1,165,500	—	1,165,500	2,085,500	300,000	2,385,500
Plates	901,100	—	901,100	1,647,000	100,000	1,747,000
Strips	205,500	—	205,500	350,500	50,000	400,500
Skelp	303,900	—	303,900	563,300	—	563,300
Total for flat products	2,837,100	—	2,837,100	5,120,700	500,000	5,620,700
Total rolled mild steel	6,883,100	20,000	6,902,100	12,094,100	1,500,000	13,594,100
Alloy steel	389,700	—	389,700	743,500	—	743,500
Steel castings	140,300	—	140,300	286,700	—	286,700
Iron castings	1,300,400	50,000	1,350,400	2,031,300	150,000	2,181,300
Cast iron pipes	428,900	200,000	628,900	829,000	400,000	1,229,000

SOURCE: Statistics for Iron and Steel Industry in India, 1964, HSL, Ranchi

Table 4 — Requirements of alloys & special steels in 1965-66 and 1970-71 (categorywise)

Type of Steel	1965-66		1970-71	
	Tonnes	%	Tonnes	%
Alloy constructional steels	50,000	13.9	124,000	18.1
Stainless and heat resisting steel	20,312	5.6	44,247	6.4
Electrical steel sheets	100,942	28.1	176,352	25.7
High speed steel, tool steel and die steel	52,811	14.7	86,083	12.5
Low-alloy high strength steel	25,436	7.1	64,195	9.4
Spring steel	80,891	22.5	132,882	19.4
Free cutting steel	29,338	8.1	58,513	8.5
Total	359,730	100.1	686,272	100.1
Stocks (1/12) of total	29,980	—	57,190	—
GRAND TOTAL	389,710	—	743,462	—

SOURCE: Statistics for Iron and Steel Industry in India, 1964, HSL, Ranchi

Table 5 — Imports of iron during 1962-63 and 1963-64

(Quantity in tonnes; Value in '000 Rs)

	Quantity		Value	
IRON	1962-63	1963-64	1962-63	1963-64
Pig Iron and Sponge Iron	839	210	655	220
Castings & Forgings unworked N.E.S.	12,346	14,078	34,547	40,264
Iron and Steel Scrap	1,737	13,281	889	6,919
SUB-TOTAL	14,922	27,569	36,091	47,403

SOURCE: Statistics for Iron and Steel Industry in India, 1964, HSL, Ranchi

The total annual production of foundry grade pig iron available for sale in 1963-64 to various foundries was about 1·164 million tonnes which is expected to increase to 1·3 million tonnes by end of 1964–65 and 1·398 million tonnes at the end of 1965–66. The anticipated availability of foundry pig iron at the end of 1970–71 is 1·538 million tonnes. In spite of these anticipated production of foundry pig iron, imports have to be made to meet the needs of foundry industry. Reports from the two consultants appointed by the Government for feasibility studies on sites for location of foundry pig iron complexes are awaiting the decision of the Government. In addition, the expansion of blast furnance capacities at Durgapur and Bhilai will also provide pig iron for sale till about 1968 when the expansion of these steel making units in these plants is expected to materialize.

Table 6 — Imports of steel during 1962-63 and 1963-64

(Quantity in tonnes; Value in '000 Rs)

	Mild Steel				Tool & Alloy Steel			
	Quantity		Value		Quantity		Value	
STEEL	1962-63	1963-64	1962-63	1963-64	1962-63	1963-64	1962-63	1963-64
Ingots, blooms, slabs, billets, sheet bars, tin plate bars and equivalent primary form	75,754	53,401	40,404	35,120	...	...	...	...
Joists, girders, angles, shapes, sections, bars R.C. rounds including tubes rounds & squares	74,487	105,762	83,351	92,587	22,168	33,106	53,624	53,624
Universal plates & sheets (uncoated)	237,823	288,808	173,150	204,263	14,110	7,405	45,465	31,208
Hoops & strips including tube strips and steel strips (coated & uncoated)	2,918	35,415	38,472	45,972	156	212	874	1,116
Plates & sheets (coated)	91,538	144,757	75,642	117,135	2,172	4,239	5,282	10,221
Wire rods and wires (coated/uncoated)	60,507	78,381	51,160	72,465	18,131	15,637	23,956	23,067
Railway rails	185,127	105,379	112,345	46,199	...	...	...	...
Sub-total of finished steel	678,650	753,502	534,120	578,621	56,737	60,599	129,201	123,262
TOTAL	754,224	811,903	574,524	613,741	56,737	60,599	129,201	123,262

SOURCE : Statistics for Iron and Steel Industry in India, 1964, HSL, Ranchi

Table 7 — Ferro-alloy requirements for alloy steel plant

Ferro-alloys		Alloy steels capacity 80,000 tons a year	Alloy steels capacity 200,000 tons a year
		(tons/year approx.)	
Ferro-chromium	(65%Cr)	10,000	26,000
Ferro-silicon	(50%Si)	2,500	6,000
Ferro-manganese	(75%Mn)	1,500	3,000
Electrolytic manganese	(99%Mn)	4,000	7,000
Ferro-tungsten	(70% W)	1,500	2,500
Ferro-molybdenum	(70%Mo)	200	450
Ferro-vanadium	(50% V)	150	300
Others		200	250
TOTAL		20,050	45,500

SOURCE : Pilot Submerged Arc Smelting Furnace (Brochure), NML

As regards steel castings, the production amounted to 60,000 tonnes in 1964 with an installed capacity of about 165,000 tonnes and the production is expected to reach 115,000 tonnes at the end of Third Plan period whilst the overall capacity is expected to be 3·75 lakh tonnes. These targets, it is estimated, should meet the requirements of the industry if the growth rate of all industries keeps a good pace.

Non-ferrous metals industry

The development of non-ferrous metals industry is of vital importance to our national economy. It is gratifying that this industry has come to occupy a prominent position in the industrial development of the country under the stimulus of our Five-Year Plans. Amongst the numerous non-ferrous metals, the most important are aluminium, copper, zinc, lead, tin, magnesium, nickel, antimony etc. With the exception of bauxite, magnesite, ilmenite and manganese, our proved mineral resources are comparatively meagre. Metals in which our country, whilst possessing some resources, is highly deficient are copper, zinc, lead etc. The metals in which we are potentially rich are aluminium, titanium, magnesium, beryllium, manganese, zirconium etc. Metals such as nickel, tin, molybdenum, tungsten either do not exist or are perhaps found in isolated uneconomic pockets, even though with more intensified and comprehensive exploration and prospecting, some economic deposits thereof may yet be discovered.

The present production of non-ferrous metals in the country relates to those of primary aluminium, copper and lead and of zinc concentrates. Chromium, vanadium, nickel, cobalt, magnesium, titanium etc. are not being produced. The 'wonder' metal titanium, used in jet aircraft manufacture etc. is being produced in the world in a meagre scale at a relatively high cost since 1950. Antimony metal is being produced from imported concentrates. There is no production of zinc metal; all the zinc

concentrate is exported to Japan in exchange for import of zinc metal. The requirement of tin is being met entirely by imports. The domestic production of non-ferrous metals at present is estimated to be about one-fourth of the country's level of consumption.

India has enough ore reserves for production of beryllium, zirconium, magnesium, chromium and manganese, but these metals are not being produced. There is no production of nickel, but copper ore of Singhbhum copper belt in Bihar contains about 0·08 nickel and the nickel can be recovered as a by-product during the course of electrolytic refining. The titaniferrous magnetites estimated at 9–10 million tons contain about 14 per cent TiO_2, 1·26 per cent V_2O_5, 2·3 per cent SiO_2 and the rest iron. During the last war, a plant at Rairangpur (Orissa) worked on these deposits but is now closed. Another metal of strategic importance is tungsten, which is not being produced in India. There are two known deposits of tungsten ore, one in Rawat Hills near Degana, Rajasthan and the other in Cendapathar area in Bankura dist of W. Bengal. The output from the Bankura mines, of wolfram was 7,570 kg. in 1964. This wolfram can be utilized for production of ferro-tungsten. This production of major non-ferrous metals and proposed capacity at the end of Fourth Plan, the requirements and imports are furnished in Table 8.

The consumption of the non-ferrous metals is rising rapidly with increasing demand of engineering and allied industries. The requirements of non-ferrous metals are expected to increase from 0·5 million tonnes in 1965–66 to 0·9 million tonnes in1970–71 and 1·3 million tonnes in 1975–76. In copper and zinc, the deficit is more than seven times and in lead it is about eight times against indigenous production. Assuming that the licensed capacities will materialize, the country will not attain self-sufficiency except perhaps that of aluminium, and will be dependent on imports.

The break-up of imports of major non-ferrous metals during the past few years is shown in Table 9.

Contribution of NML towards self-sufficiency

The shortages of raw materials and metals and alloys call for planned research and ingenuity of high order. The NML has wholly dedicated itself to the growth of metallurgical and mineral industries in the background of systematic research in basic fields of studies. The research and development programme of the NML has been fully 'industrial application' oriented, calculated to provide solution to multifarious metallurgical problems, in the execution of diverse projects both simple and complex. Systematic assessment of mineral resources, utilization of raw materials and a systematic development of substitute alloys made by optimum combination of indigenous metals and adopting specialized techniques have been carried out, a brief account of which is given below.

Beneficiation of some important raw materials

Iron ores. Comprehensive pilot scale studies have been completed in the NML on beneficiation and sintering characteristics of iron ores from the various mines in the country supplying iron ores to the public and private sector steel plants as well as for export purposes. Samples have been investigated from Noamundi, Joda, Badampahar and Gurumahisani Mines of Tisco, Barsua mines of the Rourkela Steel Plant, Bolani mines supplying to the Durgapur Steel Plant, Rajhara and Dalli Mines of the Bhilai Steel Plant, Kiriburu mines for export as well as for ore supply to the Bokaro Steel Project, Bailadila and Goa mines for export etc. The

Table 8 — Production, capacity, requirements and imports of major non-ferrous metals

(tonnes)

Metal	Production		Present installed capacity	Licensed capacity (at the end of IV Plan)	Requirements			Imports 1964 (Wrought & unwrought)
	1961	1964			1965-66	1970-71	1975-76	
Aluminium (ingot)	18,381	56,182	68,350	308,350	120,000	260,000	307,000	22,695
Copper (ingot)	8,336	9,475	9,600*	16,500* 29,400†	136,000	238,000	330,000	66,748
Refined pig lead	3,665	3,624	6,000	23,000**	64,000	144,000	220,000	34,198
Zinc	9,256‡	10,699‡	—	87,000	136,000	225,000	340,000	83,891
Antimony§	619	840	1,000	1,000	1,000	—	—	1,397
Tin	—	—	—	—	8,000	11,000	15,000	6,252
Nickel	—	—	—	—	5,000	25,000	46,000	2,467

*Fire Refined Quality Blister, copper

†Electrolytic Copper

**Tundoo Smelter at 11,000 and a private firm at Calcutta for 12,000

‡Concentrates

§Metal produced from Imported Concentrates

SOURCE: Eastern Metals Review, Annual Number, 1965 Perspective Planning Divn Estimates, Engineering Association Hand Book, July, 1964 Economic Times, Nov. 3, 1965

Table 9 — Import of base metals in terms of values

(Rs crores)

	1961	1962	1963	1964
Aluminium	7.77	10.39	6.28	6.82
Copper	22.01	24.64	26.74	23.79
Lead	2.27	2.83	2.95	5.04
Zinc	8.31	8.00	9.12	9.53
Tin	4.17	5.64	4.85	9.51
TOTAL	44.53	51.50	49.94	54.69

SOURCE : Eastern Metals Review, Annual Number, 1965 & Economic Times, Nov. 3, 1965

economic evaluation of beneficiation in terms of savings in blast furnance practice by using beneficiated iron ores has also been made.

Broadly on the basis of the investigations completed and flowsheets prepared in the NML, iron ore beneficiation plants are being contemplated at Barsua, Bolani, Noamundi, Goa, Bailadia, Kiriburu etc.

Fluorspar. The fluorspar requirements of India were till now wholly met by imports. This situation is now changing with the recent discovery of large reserves of fluorspar in Rajasthan and Gujarat but these are of poor grades, and are unsuitable as mined for metallurgical purposes. Comprehensive studies on samples of low grade fluorspar from Rajasthan and Gujarat, have shown that it is possible to obtain a high grade flotation concentrate suitable for acid, cryolite and metallurgical purposes. The Gujarat Mineral Development Corporation is proposing to set up with the help of the NML a fluorspar beneficiation plant at Ambadunagar in Gujarat.

Limestone. As high grade limestone is not available in the vicinity of the iron and steel plants, the necessity has arisen for beneficiating the the low grade limestone to make them suitable as flux for steel making. Based on extensive pilot plant studies made in the NML on behalf of the Tisco and Hindustan Steel Ltd, it has been established that low grade limestone can be upgraded by flotation to give a high grade concentrate of low insoluble content acceptable to the steel industry. The concentrates which are in form of fines could be agglomerated by pelletizing for use in steel-making and successful plant trials are in progress in Tisco's steel melting furnaces, employing these pellets.

Based on the recommendations given by NML, Tisco are setting up a Beneficiation Plant to treat 250 tons of limestone per day.

Manganese ores. The NML has made a countrywise study on the amenability of low grade manganese ores to beneficiation. Ore samples from Andhra Pradesh, Maharashtra, Madhya Pradesh, Mysore, Orissa and Rajasthan were investigated. The findings are that majority of these ores can be utilized for ferro-manganese production. The NML also advised a number of State Governments and commercial enterprises in putting up large-scale plants.

Copper ore. The NML at the instance of National Mineral Development Corporation who are engaged in the setting up a coppers melting unit at Rajasthan, has successfully developed the technique for upgrading

the copper ore from Khetri, Rajasthan containing 0·8 per cent copper to a grade of 24 per cent copper. Based on this investigation, suitable flow-sheet has been recommended to the NMDC.

Chromite. With a view to utilizing the country's low-grade chrome ore deposits, extensive work has been conducted on the beneficiation of the chromite ores by ore-dressing and thermal methods. It has, however, not been possible to upgrade the chromite ores to metallurgical grade by ore-dressing methods alone due to the intimate association of iron and chromium in the chrome spinel. However, the beneficiated product can be suitably used for refractory and chemical industries. By thermal beneficiation techniques, the low-grade chrome ores have been successfully beneficiated to metallurgical grade.

Graphite. A number of low-grade graphite samples from various localities were investigated to determine their suitability for production of graphite crucibles. Samples from a locality was successfully beneficiated and the flow-sheet evolved is now implemented by a commercial firm which is engaged in graphite crucible manufacture.

Lead-zinc ore. A sample of lead-zinc ore from Zawar mine was also beneficiated and suitable flow sheet was suggested for pre-concentration of run-of-mine ore.

Production of ferroalloys

The NML has undertaken a long range research programme on the development of technique and production of ferro-alloys from indigenous raw materials. The Laboratory is already meeting the tonnage requirement of different types of ferro-alloys for ordnance establishments. High and low-carbon ferro-chrome, carbon-free ferro-chrome, ferro-aluminium etc. have been produced on tonnage scale for the first time in India and supplied to ordnance factories. Besides, the Laboratory has produced ferro-tungsten, ferro-titanium, nitrided ferro-alloys etc. by alumino-thermic process and can supply the entire requirement of defence establishments.

Development of substitute alloys

In the context of shortage of metals like copper, zinc and lead, and the sizable demands of the defence, the possibility of replacement of scarce metals with metals that are more easily available, assumes greater importance especially in view of tight foreign exchange position. During World War II, considerable strides were made in different countries to develop substitute alloys, such as the low tungsten high speed steels, substitute EN series of alloy steels with much lower alloy contents etc. The NML has right from its inception, embarked upon some major research and development theme substitute alloys and alloy steels which are enumerated below.

Nickel-free austenitic chromium-nitrogen manganese-copper stainless steel. Based on totally available indigenous raw materials, the substitute nickel-free stainless steel was successfully developed and produced on a tonnage scale. Structural, physical and corrosion resistance properties of these stainless steels in different media were comprehensively investigated and found to be comparable to those of the standard 18/8 types. The research findings of the NML have also been confirmed by eminent scientific and research organizations, such as the British Iron and Steel Research Association, UK and others in the USA.

These steels possess excellent deep drawing properties consistent with high tensile strength and adequate ductility for different fabrications. Industrial trials were successfully made on the manufacture of household utensils by deep drawing and pressing methods. Pressure cooker lids requiring special springy characteristics for preventing the escape of steam under pressure were successfully produced. These steels can also be used for railway fittings, hospital wares, dairy equipment, decorative and architectural parts, steel furniture, high strength structural members etc. These steels can thus replace the standard 18/8 austenitic stainless steels in a large variety of applications thereby effecting a saving of considerable amount of foreign exchange. The manufacture of these nickel-free stainless steels will be taken up in the Alloy, Tool and Special Steel Plant in the Public Sector.

Nickel-free coinage alloys. The two and three paise coins recently introduced by the Government of India are another achievement of the NML in the field of manufacture of substitute alloys and it is the result of collaborative research and development work undertaken between the NML and Government of India Mint at Bombay. In view of the acute shortage of copper and total absence of nickel in India, the NML undertook concerted research and development work and evolved this new coinage alloy based on aluminium-magnesium alloy containing 3·5 per cent magnesium. By adopting this new alloy developed by the NML for the 3 and 2 paise coins, the country would conserve not only considerable amount of foreign exchange but also promote the use of indigenous non-ferrous metals for the production of probably one of the most indispensable applications in the coinage usage. Substitution of nickel in higher denomination coins by manganese is under active investigation and encouraging results have been obtained.

Nickel and cobalt-free electrical resistance alloys. Conventional types of heating elements used for domestic or industrial heating purposes contain high percentages of nickel and cobalt, neither of which is available from indigenous resources. The NML after a comprehensive investigation has developed compositions entirely free from nickel and cobalt, equivalent in properties to the imported materials. Heating elements fabricated out of the compositions developed, have withstood satisfactory service trials. The process developed has been released for industrial scale production.

Development of substitute alloy steels. Objectives of this Project are based on the basic themes to develop indigenous substitute alloy steels eliminating as far as possible alloying elements, such as nickel, molybdenum, tungsten, cobalt, etc. resources of which do not exist in India ; such substitute alloy steels through judicious combinations of indigenous alloying elements and optimum heat treatment should conform to the requirements of physical properties and specific service performance characteristics of standard alloy steels.

Aluminizing of steel. Aluminized steel is better corrosion-resistant than the galvanized material. Viewed in this context and also keeping in view that the country's entire requirement of zinc is met by import, the NML undertook a comprehensive research scheme on the development of suitable techniques for the production of aluminized steel. Extensive work conducted in the laboratory had resulted in the successful formulation of three processes of aluminizing which essentially differ in the types of flux used. To work out the economics of the process and to determine the

feasibiltity of the methods for commercial production, a pilot plant was designed and fabricated in the Laboratory and highly successful pilot plant trials were conducted. Samples of aluminized wires produced at the pilot plant were sent to British Iron and Steel Research Association who has reported that the samples were exceptional in quality and set a very high standard. This process has been leased out to as many as twenty-nine firms for commercial production of aluminized steel articles.

Bimetals. With the development of electrical industry in India, the need for bimetal is increasingly felt but the entire requirement is still met by import as its production techniques are closely guarded secrets. Details of the technology of production of all ferrous thermo-bimetals (i. e. thermo-bimetals containing ferrous alloys as high and low expansion component) were worked out in detail. Two general purpose bimetals, one for application up to 250°C. and another up to 350°C. have been successfully produced and the material can be manufactured in India with the technical know-how developed at the Laboratory which has been released for commercial scale production.

Tinless bearing alloys. Tin is extensively used in the manufacture of bearing metals. Due to nonavailability of tin in India, investigation was conducted with a view to develop copper base bearing alloy to replace tin. A bearing of zinc-aluminium-copper alloy has been made and is undergoing service trials.

Manganese bearing brass. The low production of copper in India due to limited availability of workable deposits of the ore has resulted in import of huge tonnage of the metal to meet the country's requirement. To minimize the use of copper, the NML has developed substitute brass containing manganese, in which the copper content has been reduced very appreciably. Utensils fabricated from this substitute brass have shown properties comparable to those of conventional brass utensils and can be utilized in their place.

Magnetic material. Most of our requirements of permanent magnets are met largely by imports. The general compositions of the Alni, Alnico and Alcomax type of magnets are well known and can be industrially produced by casting or by powder metallurgical processes. Although the casting is relatively simple, the difficult part is the specialized heat treatment techniques required to confer the optimum magnetic properties. These techniques have been thoroughly studied in the NML. The Laboratory has also developed the barium ferrite type of ceramic magnets. These magnets can be produced from indigenous raw materials and most of the machinery required are also available in India. A unit has been set up in the Laboratory to manufacture Alnico, Alni and Alcomax types of permanent magnets so as to meet the requirements of the industries. The process for production of Alnico type permanent magnets developed at the Laboratory has been released for commercial exploitation.

Production of non-ferrous metals and alloys

Electrolytic manganese metal. This finds considerable application in the production of nickel-free stainless steel, nickel-free coinage alloys, high and low-expansion alloys etc. There was no commercial production of this metal previously. Extensive laboratory scale investigations had formulated the development of a process for the successful production of metal of 99 per cent purity from low-grade ores and initially a semi-pilot

plant of 32/lb. day capacity was set up and electrolytic manganese metal has been successfully produced. A pilot plant for producing 100 lb./day of electrolytic manganese has been installed and full scale production is underway.

Electrolytic manganese dioxide. A process has been developed at the NML on the production of high purity manganese dioxide from low grade manganese ores. The product was tested by a leading American firm who have commented most favourably on the quality of the material. The material has been successfully produced on a semi-pilot plant scale and a pilot plant for 100 lb. of the product per day is in operation and a small quantity has been sent to Defence authorities for trials. Both the processes on electrolytic manganese metal and manganese dioxide have been leased out for commercial production.

Magnesium metal. Magnesium, which is indispensable in the production of light alloy for aircraft and used in metallic form for strategic military requirements, has been produced successfully for the first time in India on laboratory scale in the NML. The present requirement of this metal is met by import. The Laboratory has put up a pilot plant to produce magnesium metal (25 lb./day capacity) as well as magnesium powder to meet the requirement of the ordnance factories.

Aluminium-bronze. Super-duty aluminium-bronze castings of tensile strength of the order of 60 kg./mm.^{2} and minimum elongation 20 per cent were required for 25 kV. traction overhead equipment in the Indian Railways Electrification Project. At the instance of the Research, Design and Standards Organization, Ministry of Railways, the work was taken up to standardize the methods of melting and casting in detail so as to meet the specifications laid down by the French Consultants for the Railway Electrification Project, so that the railway workshops can undertake the casting of such alloys. After thorough investigation, the procedure to be employed for melting and casting to get the desired properties was furnished to the Railway Research, Design and Standards Organization and this work has been acknowledged as a valuable contribution for applications in over head electrical fittings in their electrification projects.

Development of light metal alloys

The NML has initiated a project in the development of aluminium based alloys from indigenous raw materials including the use of rare earth group of metals. Binary aluminium magnesium alloys containing high magnesium (7–10 per cent) are usually not readily hot workable. Work was done to improve the hot-workability of these higher Al-Mg alloys by the addition of rare earth residues, such as misch metal and it was found that alloys containing 7–9 per cent Mg can be made hot-workable by the addition of 2–3 per cent misch metal to the alloy melt. The wrought alloys have shown tensile strengths of the order of about 30 tons/sq. in. (47–25 kg./mm.) which are comparable to mild steel.

Synthetic cryolite

Synthetic cryolite essential for aluminium production has been produced from beneficiated fluorspar and a pilot plant for the production of 50 kg./day capacity has been set up.

Recovery of zinc from dross

Till now there has been no recovery of secondary zinc metal production and drosses from the galvanizing baths could be successfully utilized for production of the metal. It has now been established by the NML from the laboratory and pilot plant scale experiments that it is possible to recover zinc from dross by distillation at atmospheric pressures without the use of special imported retorts. The process can be easily adopted for treating 100–200kg. dross per batch by galvanizers in the vicinity of their plants. For large plants, vacuum distillation is well suited under Indian conditions. Based on the technical know-how developed by the NML and its project report, the Tisco and the Indian Tube Co. are setting up a full scale plant for recovery of zinc from dross in technical collaboration with the Laboratory.

Electrolytic recovery of tin from tinplate scrap

It is estimated that about 40 per cent of world's output of tin is used in making tin plates. The production of tin, mostly in the developing nations in Asia, Africa and South America has had static or declining production in recent years due to various reasons. There is no production of primary tin in the country; hence the recovery of tin from the scrap assumes importance. In this context, the NML has developed a process for the recovery of metallic tin by electrolytic detinning from tinplate scrap.

Electro-slag melting of steels

Electro-slag melting is employed industrially in advanced countries for the production of alloys, such as ball bearing steels, heat resistant steels, stainless steels, etc. The simplicity and the ease of operation has aroused great interest in the metallurgical field. For vacuum melting, India will have to depend for years on the import of entire equipment needed for vacuum induction melting while in the process of electro-slag remelting, no vacuum equipment is needed. The low voltage transformers, voltage stabilizers and automatic electrode regulators can be well met indigenously. The NML has successfully developed the technical knowhow of the process especially suited to Indian conditions. This can be easily implemented on industrial scale for manufacture of ball bearing steels etc.

Development of iron powder

The applications of iron powder for cutting flame scarfing of massive steel castings particularly alloy steel and stainless steel castings are progressively increasing, employing specially designed cutting nozzles.

Besides flame cutting and scarfing, pure iron powder is also used in the manufacture of iron powder, coated welding electrodes in Europe and USA. It is also used extensively for the manufacture of sintered bearings through powder metallurgy techniques. Present requirements of iron powder for autogenous cutting in India are met entirely by imports mostly of Swedish origin.

India has large deposits of high grade iron ore in which pockets of very fine iron ore known as 'blue-dust' are met with during mining operations. In Singhbhum-Bonai area about 10 per cent of 'blue-dust' is obtained during mining. These iron ore fine lumps are fragile in nature and easily crumble down to iron ore powder. The possibilities of utilizing these ore fines for

the production of iron powder were investigated at the NML and a suitable technical 'know-how' has been developed for industrial scale applications.

Sponge iron

The 'blue-dust' have also been successfully utilized for production of sponge iron. There are several direct reduction processes but under Indian conditions most of them are metallurgically impracticable and economically unacceptable, considered in the context of relative lack of gas and oil in natural supplies. The reduced iron pellets prepared by the process developed at the NML can be readily employed for the production of high grade alloy, tool and stainless steels — the reduced iron is of purity over 96 per cent. The process is metallurgically feasible and economically acceptable.

Development of refractories

With the steel ingot production reaching the higher targets as formulated under the successive Five-Year Plans, there will be a corresponding rise in the demand for refractories which form the backbone of iron and steel as well as metallurgical, glass and ceramic, cement, and kiln brick industries. Refractories are used as lining materials for industrial furnaces and other high temperature operation. A large number of refractory products such as magnesite, chrome-magnesite, mullite, zircon, sillimanite and carbon refractories have been developed utilizing indigenous raw materials.

Carbon and clay-bonded graphite crucibles

Techniques were developed for producing high quality carbon bonded and clay-bonded graphite crucibles. The crucibles produced at the NML were found to withstand a much greater number of heats than the imported crucibles under identical conditions. The processes which are covered by patent rights have been leased out to a number of firms, who are actively engaged in the commercial production.

Dense carbon aggregate

Dense carbon aggregate suitable for production of Soderberg paste has been successfully developed in the NML mostly from indigenous raw materials. The process developed has been released to the industry.

Submerged arc welding flux

The flux for submerged are welding is imported at present. The NML has developed a technique for preparing the flux from indigenous raw materials and the material thus produced has given very satisfactory results in actual welding trials. The method has been released for commercial scale production.

Symposium

The subject of substitute alloys has always tended to be somewhat controversial adjudged on the basis of indigenous availability of the primary metals not only in relation to metallurgical acceptability of the substitute alloys but also vis-a-vis their production economics, consumer acceptance and serviceability. The scope of research in such a field would

be vast indeed even in its reference to diverse metallurgical alloys, wherein such substitution could successfully be introduced in times of both peace and war emergencies; in either case, the scope of potential substitution will cover a wide spectrum. As such, the diverse substitutional factors have to be rationally and scientifically examined to establish their industrial scale implementation, particularly in the context of Indian conditions. With a view to focusing attention on multitudinous aspects of 'Metallurgy of of Substitute Ferrous and Non-ferrous Alloys', a symposium is being organized by the National Metallurgical Laboratory in 1966, the deliberations of which it is hoped will go a long way towards implementation for projected needs of the country.

In the role to attain self-sufficiency in the mineral and metal industries, the progress at the NML has been significant, steady and rewarding.

Recommendations

Mineral exploitation. A detailed survey of the minerals especially those of non-ferrous metals has to be taken up on an urgent basis to discover large, commercially workable deposits.

It is good that the Government has finalized arrangcments with the USA, USSR, and Canada for assistance in an extensive programme of survey and exploration of mineral resources during the next plan period with a view to pinpoint areas favourable for prospecting copper, nickel, zinc and lead. Even uneconomical deposits of strategic metals like molybdenum, tungsten etc. should be proved and expedient measures adopted to exploit to the maximum at the earliest possible.

The different types of low grade ores particularly of manganese, chrome, graphite, limestone, pyrites etc., need beneficiation both for increased eeonomie production of the metals and for export and industrial applications. Beneficiation should receive high priority and the industry should be made to realize the importanee of beneficiation and avail of the expert facilities available in the NML which has a fully integrated Pilot Plant to obtain technical, operational and economic data or mineral beneficiation cylces with a view to their implementation on industrial scale.

The mines should be fully exploited for increased production by devising ways and means so that the plants could be ensured of an increased supply for working to full rated capacity.

Increase in present production capacity. The present production of existing units is much less than their rated capacities such as for lead with an installed capacity of 7,000 tonnes per annum, antimony at about 1,000 tonnes per annum the production is only of about 4,000 and 800 tonnes respectively. The production must therefore be increased immediately to its rated capacity, even if it necessitates import of concentrates.

Even in the case of aluminium, where it is expected to attain self-sufficiency, the high cost of raw materials and dependence on their imports stand in the way of bringing down the production cost. This in turn increases the cost of production of semis. As semis can be exported at increased quantities with less cost of production, this needs immediate consideration.

The raw materials for aluminium are bauxite, calcined petroleum coke, cryolite, aluminium fluoride, caustic soda and electrical energy. The

development of power is already engaging the attention of the Government and with the envisaged expansion the power supply should be guaranteed adequate for working the smelters to the full rated capacity. Petroleum coke, required at about 0·75 ton per ingot ton of aluminium, is being supplied at present by the Digboi refinery but the demands of the new units will require additional production facilities. Further, the refineries should have arrangements to calcine the petroleum coke required for the manufacture of soderberg electrodes, as this would be an advantage in freight charges and as it would not be economical for each aluminium plant to have their own calcining facilities. The Soderberg paste is now partly imported and based on the indigenous know-how devoloped, steps should be taken for installation of a plant for manufacture of hard dense briquettes from petroleum coke or low ash coal which can be used as carbon grist in the soderberg pastes. There are no cryolite deposits in India but synthetie cryolite could, however, be manufactured from fluorspar which is available in substantial quantities in Rajasthan, Madhya Pradesh and Gujarat. Once the manufacture of synthetic cryolite is started, aluminium fluoride, another raw material for aluminium production, could also be manufactured.

Reclamation of drosses, swarfs, skimmings and recovery of secondary metal. In view of the shortage of primary metal, steps should be initiated to utilize the drosses and related residues from metallurgical wastes such as zinc dross from galvanizing shops, aluminium dross, brass dross, reclamation of lead and processing of electro-metallurgical residues and muds. For example, the sources of secondary zinc are the residues from galvanizing industry such as zinc dross, galvanizers ash, flux skimmings etc. Very little secondary metal is produced in the country from these sources. Zinc can be electrolytically recovered from almost all types of zinc compounds.

Utilization of red mud. Large quantities of red mud are currently dumped to waste at aluminium production plants at about 0·25 to 0·30 ton of red mud per ton of bauxite treated. The recovery of aluminium, titanium, iron and vanadium oxides as by-products from this red mud should improve overall economics of aluminium production and for recovery of the meals. Similarly, lead bullion from spent bullet cores and scrap secondary lead can be refined to the purity of 99·9 per cent lead.

Recovery of copper, nickel. In view of the acute shortage of copper, recovery of copper from scrap is of paramount importance. Recovery of valuable constituents from the tailings of Kolar gold fields, uranium recovery from the copper tailings of the Indian Copper Corporation etc. needs consideration. Recovery of lead from the silver refinery wastes, molybdenum from uranium sludge etc. also needs serious consideration.

As no nickel deposits have so far been found for extraction of the metal on an industrial scale, the possibility of extraction of nickel as a by-product assumes importance. The deposits with low nickel content of the type of copper ore in the Mosabani belt and Rajasthan seem to be promising. Due to the low nickel content, it is impossible to treat them as such for recovery of copper and nickel simultaneously but the nickel can be recovered from the matte. This problem requires detailed investigations. In this connection it is gratifying to note that about 400 tonnes of nickel may be expected to be recovered as a by-product from electrolytic refining of copper in the plant being set up by Indian Copper Corporation.

A detailed survey is to be made to assess the availability of the drosses, scraps etc. for secondary metal production and also the ways for production of metals from them.

New units. There is no production of electrolytic manganese, manganese dioxide, ferroalloys, magnesium, beryllium etc. which can be produced from indigenous sources available to a considerable extent. Plants must be installed for producing these metals.

Substitution. Self-reliance in the non-ferrous metals industry excepting aluminium cannot be expected to be achieved in spite of envisaged increased production under the Fourth Plan consequent upon the increased demands thereof. It is therefore urgent that substitution has to be envisaged. Substitution has now become an accepted policy and the progress in this line especially in the increasing use of aluminium in the electrical industry is worth mentioning. Similar substitution has also been achieved in small denomination coinage. There are a number of misgivings on the part of industry to the change-over. The subject of substitution has always tended to be somewhat controversial adjudged on the basis of indigenous availability of the primary metal not only in relation to metallurgical acceptability of the substitute alloys but also vis-a-vis their production economics, consumer acceptance and serviceability.

Substitution by aluminium. Aluminium, the one non-ferrous metal whose resources are abundant in India, on account of its versatile properties, figures as a principal substitute material. Aluminium foils are good substitute for lead, tin, etc. and aluminium electrical conductors are fast replacing copper particularly in India. A certain degree of switch-over to aluminium has already been accomplished by the Cable Industry, such as replacement of bare copper conductors by aluminium conductors, substitution of copper by aluminium in heavier VIR and PVC wires, replacement of copper and copper base alloys by aluminium and other alloys for switch-gears, substitution of paper-insulated cable based copper wire by aluminium wire etc. Aluminium can replace lead for cable sheathing with economy in first cost and economy in maintenance. The switch over has resulted in a saving of nearly 30,000 to 40,000 tons of copper per year.

Substitution by aluminium may require some modifications in manufacturing techniques but in view of the present situation, this change-over must be adopted to even at the expense of importing machinery and equipment wherever it is considered absolutely essential.

As an alternative to galvanizing, aluminizing should be encouraged. Even with the setting up of proposed plants in the country, the smelting capacity of zinc in India would be far short of increasing requirements anticipated at about 185,000 tonnes by end of 1965–66, which is likely to increase further.

The use of aluminium and its alloys in transport vechicles, lithographic plate industry, canning and packing industry, in the field of armaments for manufacture of cartridge case etc., aluminium-magnesium alloys for coinage, as substitute for 'duralumin' alloys, needs immediate encouragement and steps must be taken to implement the same.

There are many other applications in which aluminium can be substituted such as in building industry etc. The Report on 'Substitution of Imported Copper and other Non-ferrous Metals by Aluminium and other

Indigenous Metals' by Dr B. R. Nijhawan and Shri K. N. P. Rao, is already with the Metals Committee of CSIR and it is hoped that the recommendations made therein will receive immediate implementation.

Substitute solders. Due to complete dependence on imports for tin, attempts should be made for the manufacture of soft solders as substitutes for standard tin-lead compositions. Such substitute solders have been developed and this needs immediate consideration.

Canning and packaging industry. Canning and packaging industry must resort to the use of aluminium and plastics to a very great extent

Rationalization of industrial designs and specifications. During the last world war, substitute EN series of alloy steels with much lower alloy contents, low tungsten high speed steels etc., were developed. These steels were due to the efforts to rationalize the steel specifications with the object of making a very substantial reduction in the number of British Specifications and at the snme time providing a schedule of special and alloy steels to cover the requirements of Defence and/or industrial usage.

In view of the anticipated shortage in steel availability and the shortage of alloying elements like cobalt, nickel etc., a review of the categories of steels that can be substituted has to be made besides rationalization of industrial designs and specifications to cut down the use of non-ferrous metals, especially copper. It is considered that in the entire range of a manufacture of electric motors and transformers, specifications for copper winding wire are not necessary and hence the Indian Standards may be revised. In this work of rationalization of steels, the NML is actively collaborating with the Indian Standards Institution to meet the pressing needs of defence and industries.

Electrical resistance wires. Kanthal and Nichrome grade electrical resistance wires which are being imported can be produced indigenously by using substitute alloys for these wires, for which the technical know-how has already been developed by the NML.

Constantan/Eureka electrical resistance wires are required for wire wound resistors and potentiometers. Manganin can be advantageously used in place of Constantan as Constantan contains 43 per cent nickel while Manganin contains 4 per cent nickel. By using Manganin, it will be possible to cut down the nickel requirements. Manganin is at present imported and needs development work in the country in order to cut down the much needed nickel.

Imports and exports. In spite of the projected installed capacity during the Fourth Plan period to increase the indigenous production of base metals, import dependence will definitely bound to continue. It is quite natural for a developing nation such as ours. In view of the shortage of availability and the increased prices in the world market, and tight foreign exchange position, ways and means to import as large a tonnage as far as possible within the foreign exchange allocations have to be made and priorities allotted keeping in view the increasing export possibilities of the semi-manufactured goods especially those of non-ferrous metals. Aluminium manufactured goods require special emphasis as these can be exported in increasing quantities.

Steps should be taken to save imports by cutting out all those uses which are non-essential, such as the use of imported copper at a high

price for making domestic utensils and hardware. Aluminium and its alloys should be encouraged.

It is also worthwhile to study the import of concentrates from rupee area countries for utilization of the plants to the full rated capacity.

Setting up of a plant for export of processed alumina to countries like Japan, Norway, Switzerland etc., who have smelting capacity without any bauxite resources of their own needs serious consideration and implementation, so that valuable foreign exchange can be obtained.

General

The Report of the Technical Committee set up to advise the Government on various steps towards raw materials preparation and technical improvements for improved iron production headed by Dr B. R. Nijhawan is already with the Government and the valuable recommendations should go a long way in improving the iron production in the country. The recommendations of the Foundry Pig Iron Panel, the Report of which is now with the Government, should also make it possible to meet the requirements of the foundry industry.

A number of committees such as Steel Cost Committee, 'Planning Cell' in the Ministry of Steel & Mines, Special Cell for import substitution of machinery parts, Study Groups of the Planning Commission to indicate the directions in which defence needs are to be met, the Committee of General Managers of Public Sector Steel Plants to help in the development of Swadeshi Steel Plant, have been set up by the Government and the findings of these Committees will go a long way in devising ways and means for increased economic productivity and achieving self-sufficiency in the country's requirements of iron and steel and non-ferrous metals.

Conclusion

In India, if the hard core of the Second Five-Year Plan has centred round the development of iron and steel industry, the industrial growth of light metals and their alloys may well claim this place of pride during the Third Plan. The current trend of thought relates to the scaling up of production of aluminium, copper, zinc, lead etc. The production of magnesium, a metal important in supersonic age and for defence purposes, has not found a place and the production of other metals such as titanium, beryllium, chromium etc., despite their classic resources in India judged from metallurgical standards and reserves well established, have not been given the due share they deserve.

The research activities of the NML are essentially practical in nature. The NML has made significant contributions to mineral and metallurgical developments in India, to make the country progress towards the goal of self-sufficiency in her metal and mineral requirements.

Substitute Aluminium Alloys in Chemical Industry

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In the pre-independence days, one of the major consumers of non-ferrous metals and alloys, was the household utensils industry. With the development of industries, there has been a rational redistribution of the needs for them. The engineering needs have been growing at a much faster rate than the growth of the local resources and year after year there has been an increasing tempo of imports to meet the needs.

Whereas the plans for production of ferrous items have been vigorously persued and have born fruit to meet at least the basic needs, the development of non-ferrous sector is conspicuous by a very slow rate of development. It is generally agreed that the country's resources of the non-ferrous materials are obviously inadequate except for aluminium; and that imports of essential non-ferrous goods would be permanent feature of our national economy.

Amongst the users of bulk of the imported metals, the general engineering industry and the chemical industry are the major customers of special metals and alloys with uncommon specific properties. The chemical industry specifies not only structurally strong materials of construction, but those which are simultaneously corrosion resistant to the specific conditions. A great number of ferrous and non-ferrous alloys and alloy groups have been developed specially to meet the needs of the chemical industry. A major bulk of these are made up of various members of the stainless steel family, copper and its alloys and nickel and its alloys. The rest is made up of lead, tin, zinc, the rare metals and their alloys. Their formulation and usage is pretty well standardized, and their mechanical and chemical properties have been very well studied.

Of the metals and alloys that have made a name for resisting sever corrosive conditions, the various grades of stainless steels probably find wider application than all others combined. For this reason, the first impulse of many engineers when confronted with a sever corrosion problem is to recommend either 303 or 316 type stainless steel, or if these have failed, to specify higher nickel-chromium steels. A better understanding of the nature of stainless steels should indeed serve as a brake to their indiscriminate use.

That a highly reactive metal like aluminium could be discussed as a material of construction to combat corrosion in chemical and other industries needs elaborate scientific explanations. That this metal and its

alloys have been in successful use with such strong acids as the fuming nitric acids on one hand and ammoniacal liquor and ammonia on the other is an established fact. A great many conditions in between these two extremes can be successfully handled by aluminium which makes many to look towards this metal as a possible solution to their problems.

An attempt has been made therefore to focus the attention of metallurgical and chemical engineers to the possibilities offered by aluminium and its alloys in the field of corrosion resistant materials of construction.

The scope of the paper is to reiterate and to bring out the present day status of this metal. This has been done by discussing the physical, mechanical and chemical properties of the metal and its alloys; their corrosion resistance to specific chemical corrosives, their standard alloys and their industrial applications.

A point to be remembered is that corrosion is a phenomena which is very sensitive to the presence of minor impurities which may accelerate or inhibit corrosion. The latter in trace quantities are industrially used for controlling the corrosion which otherwise would most certainly have taken place. Trace corrosion accelerators are also equally effective, in that a medium which would have been completely harmless without them shows a disastrous response in their presence. The statements in this paper are therefore general in their nature. As in the application of all other metals, it is most advisable to test the feasibility of the use of aluminium to specific and particular conditions before taking the plunge.

Aluminium alloys : Some physical considerations

The development in aluminium alloys has been so rapid during the past few years that a more elaborate, four-digit designation system had to be evolved. The four-digit system as worked out by the Aluminium Association is shown below[1].

Type of aluminium alloy	Number group	Example
Alumininm 99·0%	1XXX	1100
Copper	2XXX	2024
Manganese	3XXX	3003
Silicon	4XXX	4043
Magnesium	5XXX	5052
Magnesium & Silicon	6XXX	6061
Zinc	7XXX	7075
Other metals	8XXX	

Some of the above alloys have been developed to fill in the special needs of high strength and corrosion resistance.

Alloy 2219 was initially introduced as an aircraft forging alloy for highly stressed parts operating at high temperatures. But it soon demonstrated other outstanding characteristics: high strength, good weldability, and resistance to stress corrosion cracking and has been suggested for transport industry, missile applications and for chemical industry[2].

The old designation of aluminium alloys are as follows[3]:

1-S	99·996% Aluminium very pure metal
2-S	99·0%+Al; commercial pure alloy; general purpose
3-S	1·2% Mn alloy, corrosion resistant, weldable, strong for cooking, food and chemical industry
11-S	5·5% Cu, 0·5Pb, 0·5% Bi; machinability; screw stock
14-S	4·4% Cu, 0·8% Si, 0·8% Mn, 0·4% Mg; high strength, heavy duty forgings, aircraft fittings
17-S	4% Cu, 0·5% Mg, 0·5% Mn; high strength (30 tons p.s.i.), corrosion resistance
18-S	4%Cu, 2% Ni, 0·5% Mg; for strength at elevated temperatures
24-S	4·5% Cu, 1·5% Mg, 0·6% Mn; higher strength
32-S	12·5% Si, 1·0% Mg, 0·9% Cu, 0·9% Ni; for piston heads, because of low thermal expansion, forgeability
56-S	5·2% Mg, 0·1% Mn, 0·1% Cr; wire products of corrosion resistance
61-S	0·25% Cu, 0·6% Si, 1·0% Mg; 0·25 Cr
63-S	0·4 Si; 0·7 Mg
72-S	1·0% Zn
75-S	1·6% Cu, 0·2% Mn, 2·5% Mg, 5·2% Zn, 0·3% Cr
R-303	1·2% Cu, 2·5% Mg, 6·5% Zn, 0·1% Ni, 2·25% Cr
113	7% Cu, 2·0% Cr
122	10% Cu, 0·2% Mg
A-132	0·8% Cu, 12% SiA, 2% Mg, 2·5% Ni
220	10% Mg
355	1·3% Cu, 5·0% Si; 0·5% Mg

The last five alloys are some of the typical cast alloys; the rest are wrought alloys.

Corrosion resistance of aluminium alloys

Before the industrial uses of aluminium and its alloys in chemical industry are catalogued, it is worthwhile to appreciate some fundamental aspects of the behaviour of aluminium in corrosive environments.

Basically aluminium is a highly reactive metal. This can be well gauged by the heat of formation of its oxide which is 389.5 kcal./mol. The partial pressure of oxygen in the ordinary air is enough to initiate, and carry to completion an oxidation reaction which would convert the metal to its oxide completely in a matter of minutes. Thermodynamically it is logical and reasonable. The fact that it does not burn itself off in spite of its highly reactive nature, and further that it can successfully combat many a corrosive environments needs to be explained away.

The secret of stability and usefulness lies in an ever present, and self-healing oxide film on its surface which is endowed with a group of remarkable properties. This film of its oxide is first of all almost invisible because of its transparency. In needs elaborate efforts to prove that it is there at all. Secondly, the film is very dense and impervious to gases and

liquids, completely shielding the reactive metal beneath from any access to the corrosive environment. Thirdly, it is hard and abrasion resistant and can be synthetically produced with much enhanced abrasion resistance that a steel nail would not be able to scratch it. Fourthly, the film is self-healing in presence of air or oxygen bearing environments; it is further very pliable, strongly adherent and does not peel off due to mechanical or thermal stresses. These are very remarkable properties not shared so abundantly or widely by other metals. It is no exaggeration to say that aluminium owes its commercial existence to this film.

Manipulation of some specific properties of this film has been made possible by electrolytic or chemical treatment. Anodising has been popularly used as a means for obtaining the film with desired properties by adjusting the conditions of electrolysis. Films with a hardness of 500 VPN can be easily produced. This has been achieved by changing the anodising conditions principally in the direction of high current density and refrigeration of the electrolyte.

It is obvious that the stability of the metal is dependent on the stability and corrosion resistance of the oxide film. The corollary that follows is that environments that are unsuitable to the oxide film are automatically corrosive to the metal. Further, the conditions that would hamper the reformation of the film due to among other things, paucity of oxygen, would prove corrosive to aluminium, unless some effective inhibitor is added as tannic acid and Rosin to inhibit attack by HCl[4].

Galvanic considerations

Another important aspect of aluminium is its high electrode potential which being highly anodic, allows the metal to dissolve away sacrificially when in contact with most other metals. In a dilute (53 g./l.) of sodium chloride solution, the electrode potential of aluminium and its alloys is quite near to that of zinc (1.0 V.) ranging between 0·96 and 0·70, as compared to 0·2 of copper, and 0·07 of nickel. Contacts between other metals and aluminium and its alloys are therefore highly disastrous to the latter except when coupled with zinc or magnesium.

Dissimilar contacts is not a consideration complete in itself. Even the alloy constituents in an aluminium alloy can set up internal electrolytic cells promoting corrosion. The electrode potentials of aluminium and some of the constituents found in the usual aluminium alloys have been known. As compared to the potential of pure aluminium (0·85 V.) those which have potentials nearabout are. (i) 4% Mg solid solution. 0·87; (ii) Mn Al6 0·85; (iii) 1% Mg_2Si solid solution 0·83 and 1% Si solid solution 0·81. Whereas Mg 5Al8, 4% $MgZn_2$, 4% Zn solid solution and 1% Zn solid solution have potentials higher than 1·0; and the following have potentials lower than 0·7 : 4% copper solid solution, $FeAl_3$, $CuAl_2$, and silicon (0·26).

Iron, silicon, copper and nickel form strongly cathodic constitutents. Of these, nickel is added only to those alloys which are meant for high temperature applications to maintain high strength and hardness under conditions where electrolytic corrosion is unlikely. Copper in solid solution changes the electrode potential in the cathodic direction whereas the intermetallic compound of Cu-Al is even more adversely cathodic. This makes the presence of more than 0·25% Cu in aluminium highly conducive to corrosion.

On the other hand manganese forms most compatible alloying constituents with same electrode potential as that of pure aluminium. Same is also true to a lesser extent of so id solutions of 4% Mg, 1% Si, and 1% Mg_2Si.

Effect of heat treatment

It becomes obvious that heat treatment would have a profound influence on the corrosion behaviour of the aluminium alloy. The heat-treatable alloys are mostly copper bearing. Age-hardened alloys aged at room temperature is not low in its corrosion resistance. But when ageing produces larger precipitates surrounded by areas depleted in copper, the latter respond vigorously to corrosive agents and lead to very rapid dissolution of the intergranular type. The other heat-treatable alloys are of the Al-Mg-Si type but here the precipitates have almost the same electrode potentials and it does not matter if the alloy has its ingredients in solid solution or as precipitates.

The above considerations also govern the choice of alloys for alcladding. In Alclad 3s the core is 3s and cladding is 72s; in Alclad 14S the cladding is 53s; for 17s and 24s the cladding is pure aluminium and for 75s it is 72s alloy. The combination is so chosen that the electrolytic compatibility of the metal constituents of the core and cladding material is ensured.

Alloywise uses of aluminium

Certain well established practices in the use of various aluminium alloys can now be well understood in light of the above discussions. In the following paragraphs the general applications of the alloy groups in the chemical and allied industries are described.

The high purity aluminium —1S is the best best material of construction from corrosion point of view, its performance becoming better with its purity. Because of its superior resistance to corrosion, as also because of its higher costs, it is perferred as a cladding material on structurally stronger core materials of lesser corrosion resistance.

The commercial —2S is a general purpose metal good for a number of miscellaneous applications involving milder corrosive conditions as neutral or near neutral chemical solutions.

In the Al-Mn series (3000 series) both the wrought as well as the cast alloys are extensively used for chemical handling in the form of sheets, tubes, piping, fittings, etc.

In the Al-Mg series the alloys like the 52S possess a high order of resistance and are in extensive use in chemical industry and for marine applications. The 56S is specially compounded for wire products. A new alloy 5083 has a tensile strength of 45,400 p.s.i., a yield point of 22,000 p s.i., and an elongation of 23 per cent. It has been estimated that weight for weight the alloys has the same strength as stainless steel and in pricing index abroad should cost less. Among the casting alloys, the 214 and 220 are more well known for their tranish proof surface and corrosion resistance.

The aluminium silicon system contributes a number of outstanding alloys particularly cast alloys of the 43, 13 and 356 type which are good for

resisting attacks by food acid waters and chemicals. The 356 has made its marks by its success in marine fittings, pumps, liquid cooled cylinder blocks and a large number of aircraft parts.

Al-Zn series produces alloys with zinc constituents having anodic potential. They are therefore used as sacrificial claddings, best known amongst which is the alloy 72S. It must be added here that the resistance to corrosion of 72S is only slightly inferior to that of 2S.

Al-Cu alloys are not known for their corrosion resistance and are not recommended for corrosive environments except for alloy 195 used for cylinder heads of air cooled engines.

Corrosive environments handled by aluminium alloys

The ability of aluminium and its alloys to combat specific chemical environments has been extensively studied and chemicals and conditions have been marked out for the use of aluminium alloys.

Like tin, lead and zinc, aluminium is an amphoteric metal even then it can handle many acidic and alkaline materials successfully.

The response to atmospheric attack varies from complete tarnish proof performance in dry clean locations to an etched and slaty appearance in industrial atmospheres in case of most of the alloys. Present day advances in the surface treatment of aluminium have made it possible to use aluminium extensively as an architectural material of great appeal and value. Similarly, the surface treated aluminium has been used for years in industrial service as stated in the petrochemical industries. It must be again stated that free access of oxygen is of great importance in the long life of aluminium and any condition which may set up oxygen-concentration cells would lead to corrosion.

Resistance to waters has also been extensively studied from such standard liquids as distilled waters, demineralized water, pyrogen free water to such highly local conditions as various lakes, rivers, seas etc. It can be concluded from these studies that aluminium is the best material of construction for manufacture and storage of distilled and demineralized water since it is neither corroded by them nor does it contaminate these liquids. It has become a standard practice to use aluminium alloys like 2S, 3S, 52S etc. for these applications.

As regards other waters, it may be generalized that waters that are essentially neutral offer no problem. Small amounts of heavy metal ions are deleterious in that they cause pitting attacks. No good correlation exists between concentration of other salts and corrosion, but it may be mentioned that the use of alclad material has been fairly successful in cooling water service and in heat exchangers. It has been concluded that the attack is stiffled as soon as the underlying 3003 metal is exposed, a sacrificial protective cell is set up. Floral or faunal attachments are a source of trouble.

With acid solutions the alloys are attacked by a number of acids in dilute condition. However concentrated red fuming nitric acid can be safely handled by the metal. Also the attack by hydrochloric acid can be successfully inhibited by the use of organic and inorganic inhibitors.

Salts that hydrolyse giving acid solutions like ammonium nitrate, ammonium sulphate etc. can also be handled by aluminium.

Neutral inorganic salt solutions can be successfully handled by these alloys. But presence of heavy metal ions can cause an attack. Inhibition of this by chromate salt is quite successful. Aluminium has been used for piping oil-well brines.

Alkaline salts and their solutions destroy the protective film and hence are corrosive to the metal as well. The only and a remarkable exception is the ammonia and ammonium compounds industry where aluminium is extensively used. Inhibition by sodium silicate or chromate can allow its use for even soda ash handling. Amines are successfully handled by the metal.

In handling of sulphur and its compounds, aluminium shows its remarkable superiority of its chemical corrosion resistance. This is particularly true of such forms as molten sulphur, sulphur vapours, hydrogen sulphide that corrode many other metals.

Aluminium alloys may be used not only because of their corrosion resistance, but also because of their ability to present an inert surface which would not decompose chemicals catalytically which many other metals do. It is primarily because of this that pure aluminium is used for handling of hydrogen peroxide and that alloys 2S, 3S, 52S etc. are used for handling mineral and vegetable oils. Similarly, aluminium and its alloys are preferred in fermentation industries (citric acid, gluconic acid, beer, etc.) not only because it resists any attack, but also because it is not toxic to the fermenting organisms.

In refrigeration industry aluminium presents a combination of its high heat conductivity with its remarkable resistance to all industrial refrigerants, like ammonia, freon and sulphur dioxide.

In dairy and food process industry the compatibility of aluminium alloys to various types of food, dairy products, fruit juices, meat, fish, vegetables, wines, beer, has been proved and utilized to a great extent. For these purposes a large number of alloys particularly 2S, 3S, 52S, 61S, and castings 43, 214, 356 etc. are very commonly used.

In the manufacture of plastics, aluminium is being used for reaction vessels, storage tanks, piping, heat exchanger and polymerizing equipment. The world's largest polypropylene of Avisun Corpn includes a 43,000 cu.ft aluminium storage structure.

In the brewery industry aluminium is used for beer kegs, fermenting tanks, malting tanks, with complete safety and confidence.

Table 1 gives the industrywise uses of aluminium made equipment.

Aluminium alloys for nuclear technology

Aluminium makes itself attractive by the following unique combination of properties for atomic usage:

1. Ability to withstand prolonged radiation without absorbing neutrons
2. Radiation damage in aluminium is very little as compared to other metals
3. Decontamination time is low; only six minutes
4. Has excellent resistance to aqueous corrosion.

Table 1 — Aluminium alloys for handling and processing chemicals[3]

Process or Chemicals	Equipment made of Al	Alloys
Acetic acid	Distillation columns condensers, piping, drums, storage tanks, tank cars; oxidizing kettles, receivers	2S, 3S, 52S, 61S, 214, 356, 406, alclad 35.
Acetic anhydride	Heat exchangers, reaction vessels storage vessels, piping, tank cars	do
Ammonium nitrate	Ammonia tanks, reaction vessels, evaporators, tanks	do
Ammonium hydroxide	Absorbers, condensers, piping	do
Edible oils and fats	Deoderizers, bleachers, stills, separators, condensers, traps, filters, pumps, tanks, piping, drums, tank cars	do
Fatty acids	Condensers, storage tanks, trays, filter presses, melting units	do
Formaldehyde	Scrubbers, receivers, storage tanks, condensers, drums, tankers	do
Glue and edible gelatin	Evaporators, tanks, piping heat exchangers, cooling towers	do
Hydrogen peroxide	Stills, condensers, receivers, piping, pumps, drums, tanks and tank cars	1S, 2S, 52S, 43, 214, 356
Naval stores	Same as above	do +61S, 214, 406, alclad 3S
Refrigerants	Compressors, heat exchangers, tubing, NH_3, SO_2, freons, evaporators, receivers CO_2, methyl formate	+61S, 214, 406, alclad 35, 17S-t4, 24S-T4,
Soda ash	Equipment for handling brine CO_2, NH_3 such as stills, piping, heat exchangers absorbers, reaction columns	2S, 3S, 52S, alclad3S, 43, 214, 356, 506
Water, distilled, deionized	Storage tanks, piping, receivers, condensers, degasifiers	do

In view of the above properties it is but obvious that it is extensively used in atomic energy applications.

It is used for fissionable materials when minimum shielding is needed.

In the more accepted technique of food preservation by atomic radiation, aluminium is used for canning the food, since it allows the radiations to pass through, and further, it can be handled within 10 min. of irradiation because of its low decontamination time.

Aluminium has been exclusively used for a number of swimming pool type of reactors.

At Brooke Haven National Laboratory a pilot plant for separation of fuel elements was constructed entirely out of aluminium.

More recently, the Yankee Atomic Electric Co.'s 485,000 kV. thermal reactor uses three large aluminium tanks made out of alloy 5052 to guard the purity of water. One tank is a 135,000 gal. primary water storage tank. The other one is 125,000 gal. safety injection tank

and a third one of 30,000 gal. is for demineralized water storage. These vessels resist attack by carbon dioxide and ammonia carried over from the steam system. They are not only virtually maintenance free, but aluminium preserves the quality of water by eliminating the risk of pick of heavy metal ions[2].

Aluminium alloys in petroleum industry

Aluminium alloys have been increasingly used for structural purposes in the construction of light weight derrics in production of crude. This application has gained prominence not only because of the ease of assembly due to light weight, but more so because of the ability of the aluminium and its alloys in handling 'sour' crude. Its striking performance was convincingly demonstrated in a famous French Oilfields which was developed during the last decade and which was as much known for its fabulous extent as much for its ability to corrode away almost all the conventional materials of construction used there. The problem was created by the very high amounts of hydrogen sulphide in the crude, nickel, copper and their alloys could not withstand the crude and the atmosphere created by it and aluminium was the only one which solved the problem.

In petroleum refining, aluminium is extensively used for combating the corrosive refinery atmosphere. The civil structures incorporating window frames, stairways, railings, treadways, roofing, siding, insulation jackets, weather-proofing in aluminium is an effective answer to highly corrosive refinery atmospheres. Aluminized steel sheets are cheaper substitutes in these environments and have also been extensively used.

In the process itself, aluminium and its alloys have been adopted for the following equipment:

Diethanolamine generator; condenser tubes for heart cut fraction (HCF); bottom coolers; light ends fractionator gasoline after cooler; solvent stripper bottom cooler; depropanizers; glycol amine reflex condensers; reformer fractionator cooler; hydrodesulphidizer (HDS); lube hydrofinisher; propane condenser etc.

Aluminium does not cause sludging of oil which usually results in the handling and storage of sour crudes. Storage tanks for such crudes are extensively made of aluminium. Insulation jackets made of aluminium do not need any maintenance at all.

Aluminium pipes are being introduced in the oil well drilling field. Recently, the Reynolds supplied a string of 4.5 in. diam. aluminium pipe for off-shore drilling in Alaskan waters. Alcoa has also been supplying similar pipes to the oil fields in Canada and Wyoming.

Aluminium in cryogenics

Aluminium retains its ductility and impact resistance, actually becoming stronger at low temperatures when many other metals become brittle and prone to rupture. This is represented below:

Metal	Structure	Ft lb. energy to break	
		At 20°C.	At 200°C.
Aluminium	F.C.C.	19	27
Iron	B.C.C.	78	1·5
Copper	F.C.C.	43	50
Nickel	F.C.C.	89	99

The unusual ability of the aluminium alloys to maintain their strength, ductility and resistance to shock loading at extremely low temperature, combined with their high conductivity high reflectivity, low emissivity, and high strength to weight ratio has made it extremely popular in the ever increasing field of cryogenics[5].

Some of the more noteworthy applications of aluminium and its alloys in this field during the recent years are listed below:

1. A 90,000 gal. capacity tank for liquid hydrogen at Douglas Aircrafts Corporation's Sacramento field station.
2. 4,000 gal. capacity liquid oxygen trailers for US Air Force; where the carrying capacity is increased by 40 per cent by using all aluminium construction.
3. Largest cryogenic tanks in the States have 325,000 gal. capacity for holding liquid oxygen and liquid nitrogen at Air Reduction Sales Co.'s plant at Butler Pa; and Acton, Mass. These tanks are in the form of spheres about 45 ft diam. lagged with about 4 ft thick perlite insulation and covered by a steel. The alloy used is 5456 in sheets of 0.312 to 0.40 in thick. An installed aluminium sphere is cheaper than the next best metal.
4. An entire tonnage oxygen plant and an air borne Dewar flask of 1700 gal. capacity have been made in aluminium[5].
5. A dry cargo ship 'Methane Pioneer' has been converted to carry liquid methane at —160°C. The tanks made of aluminium are 30 ft cubes insulated with 12 in. balsa wood.
6. Similarly, storage capacity for liquid methane at Canvery Island, England also uses an aluminium tank 50 ft diam. and 50 ft high a with a 3 ft insulating layer.
7. Recently aluminium has also been used for handling liquid helium — a real challenge.

Because of an attractive combination of most desirable properties, aluminium has become an accepted material of construction for all cryogenic applications and is regularly prescribed for handling liquid gases like oxygen, nitrogen, methane, argon, propane, ammonia, deuterium at low temperatures.

Recent uses of aluminium alloys

In fertilizer industry aluminium is being extensively used for process equipment. Urea and ammonia plants use tanks and pipes of aluminium. For air separation plant, steam plant, carbon dioxide purification plant, carbonization plant, carbamate reactors, aluminium has been extensively used. A liquid fertilizer storage tank 70 ft diam. and 48 ft high was recently built of tapered aluminium sheets. Another instance is aluminium lining to a urea column which has shown excellent resistance to corrosion.

Besides its use in bleaches, and intermediates, the most glamorous use for hydrogen peroxide is in rocketry. The biggest in the world plant is of Laporte Chemicals at Warrington, UK, uses aluminium extensively. Pressure vessels with 1·5 in. thick aluminium walls have been in use here.

The tallest aluminium structure in the world is a 200 ft prilling tower in California manufacturing ammonium nitrate. All construction around the plant is also in Al. Piping and storage is also done in aluminium.

An all-aluminium plant has been recently commissioned in UK for ammonium carbonate manufacture. Also for the manufacture of manganese carbonate of high purity, by the Leute-Dean ammonium carbonate process, most of the vessels and pipe lines are of aluminium alloys.

In Collin's process for desulphurization of coke oven gas aluminium is used for deacidifiers, heat exchangers and heating coils.

Transport of chemicals. Aluminium is extensively used for transport of chemicals over roads, rails, and waters. Chemicals which are regularly handled by aluminium alloy tank cars on US railways are given below[3].

Acetic acid 3S, 4S; Ethyl acetate Alclad 17S; Fatty acids 3S; Formaldehide 3S; Glycerin 61S; Hydrogen peroxide 1S, 2S; Naphthenic acid 3S; Nitric acid 61S; Water white rosin 3S.

More recently ALCAN has successfully tested aluminium tubular cars with a pay load capacity of 103 tons each for carrying lime, cement, alumina, gypsum, adipic acid, perchloro ethylene, polyethylene. Another of the Kaiser's design has 4 compartments with eight discharging gates, uses a 3/8 in. plates and extrusions totalling 7 tons of aluminium.

Double hulled barges of 130 ft length have been in use for carrying 13,000 bbl. of chemical liquids and juices. Canning and packing industry alone used these barges for shipment of 25,000 tons of juices in the USA.

Fabrication, design, safety, cost

The popularity of aluminium is mainly due to the following factors[6]:

1. Aluminium is an economic material to use — for the service it can give, it is good value for the money.
2. It is becoming increasingly available in a number of common forms, shapes and sizes.
3. It is amenable to easy manipulation, fabrication, welding and general handling.
4. It is easy to install because of its light weight, and after installation it needs little attention during its working life.

Today the wrought alloys are available as plate sections wires, foils, tubes, extrusions, special shapes as radial finned tubes etc. It is also available abroad as plates 11 ft wide and 60 ft long. Similarly casting as heavy as 1.1/2 tons or with precisions of 0.003 in./in. which enable obtaining smooth surfaces without the need to do any elaborate machining[6].

The more significant mechanical data are the low specific gravity, the low modulus elasticity as compared to steel, low melting point and high coefficient of expansion.

Aluminium has been now accepted and specified for pressure vessels the design stresses for various materials and forms are being laid down. Aluminium is not employed much above 150°C. The maximum specified pressure at 225°C. is 150 psig. Its cryogenic uses are discussed elsewhere.

Aluminium has an excellent safety record in industrial environment particularly where explosive gas mixtures could be sparked off. It is not a material which can be sparked off readily in practice.

The fabrication costs with aluminium should be low, as in foreign countries, particularly because of its good workability and weldability. As an example, instance may be cited where 2.3 million gal. tank measuring 128 ft diam. and 26 ft height was erected in the field out of a 1.9 in. thick alloy plates (5052 for side walls; 3003 for floor and roof; and 6061 for the structural support of the roof).

Table 2 gives an idea of cost comparison of alloys for welded unfired pressure vessels. No attempt has been made to substitute the present scarcity condition prices in India with the free market prices abroad. The comparison has been made amongst three aluminium alloys—5456, 6061T6, 3003; and two stainless steels—304 and 316, and copper[1].

Tables 3 to 5 show physical and mechanical data of wrought and cast aluminium alloys, useful for design purposes.

Table 2 — Cost comparison with other alloys

Alloys	5456	6061-T6	3003	304	316	Copper
Maximum allowable stress, psi	10,400	5,900	3,150	17,700	18,750	6,700
Metal thickness, % of 5456	100	176	330	59	56	155
Metal density, lb./cu.in.	0.096	0.099	0.099	0.29	0.29	0.32
Vessel weight, % of 5456	100	180	340	178	169	520
Metal cost/lb.	0.542	0.478	0.449	0.547	0.807	0.57
Metal cost, % 5456	100	88	83	101	147	105
Metal cost per vessel % of 5456	100	159	282	180	252	546

Table 3 — Design stress of aluminium and aluminium alloys

Material designation	Temper	Design stress, lb./sq. in. at °F. 100	200	300	400
SIB	0	1,650	1,600	1,250	1,050
B.S. 1470	1/2 H	3,000	2,900	2,350	1,600
SIC	0	2,350	2,300	1,850	1,300
B.S. 1470	1/4 H	3,500	3,150	2,650	2,100
	1/2 H	4,000	3,650	3,000	2,200
NS3	0	3,350	2,900	2,400	1,800
B.S. 1470	1/4 H	4,250	3,800	3,300	2,650
	1/2 H	5,000	4,700	4,000	3,100
NS4	0	6,250	6,200	5,400	3,900
B.S. 1470	1/4 H	7,750	7,650	6,400	4,800
	1/2 H	8,500	8,400	6,900	5,300
HS20	WP	10,500	9,900	7,900	4,400
B.S. 1470					

Partial extract from Table 12, B.S. 3274

Table 4 — Mechanical properties suitability of Al alloys

Properties of wrought materials							Suitability for					
Material designation	Nominal composition	Condition	0.1% proof stress, ton/sq. in.	Tensile strength (min. unless a range is given) ton/sq. in.	Elongation on 2 in. (min.) (material thicker than 12 S.W.G.)	Bend radius (min.) (material 12 S.W.G. & thinner thickness) t=thickness	Cold forming*	Machining	Fusion oxygas	Welding** inert gas shielded arc	Resistance spot welding	Resistance to atmospheric attack
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
SIB B.S. 1470	99.5% Al	0	—	6.0 (max.)	30	Flat						
		1/2 H	—	6.5–8	8	1/2t			Non-heat treated			
		H	—	8.5	5	1t	V	F	V	V	G	V
PIB B.S. 1477		M	—	4.0	30	—	V	F	V	V	G	V
		1/2 H	—	6.5–8.0	8	—						
NS3 B.S. 1470	Al 1.1/4% Mn	0	—	7.5 (max.)	30	Flat						
		1/4 H	—	7.5–9.5	12	Flat						
		1/2 H	—	9.0–11.0	7	1/2t	V	F	V	V	V	V
		3/4 H	—	10.15–12.5	5	1t						
		H	—	11.5	3	3t						
NS4 B.S. 1470		0	—	11.0–14.0	18	Flat						
		1/4 H	9.0	13.0	8	1/4t	G	G	G	G	V	V
		1/2 H	12.0	15.0	5	1t						
NP4 B.S. 1477	Al 2.1/4% Mg	M	—	12.0	12	—	G	G	G	G	V	V
NS5 B.S. 1470	Al 3.1/2% Mg	0	6.0†	14.0	18	Flat	G	G	F	G	V	V
		1/4H	11.0	17.0	8	1t						

Contd

Table 4 — *Contd*

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
NS6 B.S. 1470		0	8.0†	17.0	18	Flat	G	G	F	G	V	V
		1/4H	14.0	19.0	8	2t						
NR5/6 B.S. 1477	Al 5% Mg	M	8.0	17.0	12	—	G	G	F	G	V	V
		0	7.0	17.0	18	—						
HS30 B.S. 1470	Al 0.7% Mg, 1% Si 0.5% Mn	0	—	11.0 (max.)	18	Flat	—	—	—	—	—	—
		W	7.0	13.0	15	2t	G	G	F	G	G	G
		WP	16.0	19.0	8	3t	F	V	F	G	G	G
HP30 B.S. 1477		W	7.0	13.0	15, 12‡	—	G	G	F	G	G	G
		WP	15.0	19.0	8, 6‡	—	F	V	F	G	G	G
HV9§ B.S. 1474	Al-1/2%, Mg 1/2%Si	M	—	7.0	15	—	—	—	—	—	—	—
		W	5.0	9.0	18	—	G	G	G	G	G	V
		P	7.0	10.0	10	—	—	—	—	—	—	—
		WP	10.0	12.0	12	—	G	V	G	G	G	G
HF14 ¶ B.S. 1472	Al-Cu-Mg-Si	T	13.5	24.0	15	—	F	G	U	G	V	F
HF15 ¶ B.S. 1472	Al-Cu-Mg-Si	W	13.5	24.0	15	—	F	G	U	G	V	F
		WP	26.0	30.0	8	—	P	V	U	G	V	P

V=Very good G=Good F=Fair P=Poor U=Unsuitable

*Ratings for non-heat-treatable materials vary with temper, and those indicated are for material in the annealed or other optimum condition for cold forming.

**Ratings are given for correct technique and filler rod and take into account the properties of material after welding. Inert-gas welding of allonysH14 and H15 is till in the experimental stage.

†Typical figure for information only.

‡According to thickness.

§Since alloy H9 is not standardised in sheet and plate, figures for extruded round tube are given.

¶Forged test pieces.

Table 5 — Properties of casting alloys : Separately cast test bars

B.S. 1490	Nominal composition	Condition	0.1% proof stress ton/sq. in.		Tensile strength ton/sq. in. min.		Elongation on 2 in. % min.		General properties		
			Sand	Chill	Sand	Chill	Sand	Chill	Resistance to corrosion	Machin-ability	Pressure tightness
LM5	Al5 Mg	M	5.0	5.0	9.0	11.0	3	5	V	G	P
LM6	Al-12S	M	3.5	4.5	10.5	12.0	5.0	7	V	F	V
LM8	Al-5 Si Mg	M	5.0	5.5	8.0	10.5	2.0	3			
		P	8.5	8.5	9.5	12.0	1.0	2	V	F	G
		W	6.5	6.5	10.5	15.0	2.5	5			
		WP	14.0	14.0	15.0	18.0	—	2			
LM10	Al-10 Mg	W	10.0	11.0	18.0	20.0	8.0	12	V	G	P

V=Very good G=Good F=Fair P=Poor U=Unsuitable

Conclusion

The data presented in the paper brings home the versatility of aluminium and its alloys in chemical engineering applications. It is hoped that Indian fabricators will make greater use of this indigenously available material of construction.

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Aluminium Alloys as Substitutes for Tin Bronzes in Bearing Applications

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During the course of evolution and development of sleeve bearing materials, although alloys of many different metals have been suggested and used, in general engineering industry tin bronzes have found the widest application. In India scarcity of strategic non-ferrous metals like copper, tin etc. has been endemic and the problem has gained a new height of seriousness in the present state of emergency. As no difficulty is envisaged in procuring primary aluminium in this country, the Research Department of Eyre Smelting carried out experiments to find out if certain aluminium alloys could be used as substitute materials for the more conventional tin bronzes. During the days of the Second World War, nonavailability of copper and tin compelled the German Automobile Industry and the Department of Defence Production to look for substitute alloys for moderate to heavy bearing duty and due to the excellent metallurgical pıoperties of aluminium based alloys, their interest was directed to these alloys. Cast alloys of these metals were used widely as bushings and bearings in place of tin bronzes. The Research Department of Eyre Smelting has experimented with two of the more promising alloys, the first an aluminium base complex alloy and the other an aluminium-zinc-copper ternary alloy. Both the alloys offer interesting possibilities as evident from Table 1.

As no single test can indicate the suitability of an alloy as a bearing metal, it was thought that simulated performance test should be carried out under laboratory conditions. Test bearings were made from chill cast alloys of A & B while a tin bronze bearing was kept as control. The bearings had the following dimensions: Outer diam. 3 in., Thickness of bearing 1 in., Oil clearance 0.025 in.

Table 1 — Suitability factors of aluminium alloys

Alloy	Sp. Wt	Tensile strength tons per sq. in. (minimum)	Elongation % on 2 in. gauge length (minimum)	Brinell hardness number
Tandem white bronze alloy 1	3.2	9	8	45
Tandem white bronze alloy 2	4·8	19	5	95
Gun metal	8·6	16	18	70
Leaded tin bronze (8% Sn, Pb.25% P.05%)	8·8	17	5	110

One end of a horizontal roller mill was fitted with an experimental bearing, while the other end had a conventional phosphor bronze bearing —both well fitted in housings. The lubricant used was Shell SAE 40 and this was fed through lubricant spouts connected to the bearing. The assembly was run for 500 hr with regular interruptions to simulate the condition of 'stop and start' during actual use. The rise of temperature recorded at both ends after a continuous run of one hour was as follows: Alloy 1,45°C.; Alloy 2,32°C.; Tin bronze, 48°C.;

At the end of the run the bearings were taken out and examined for wear, deformation, and other surface irregularities. Heavy score marks were observed on the bronze bearings and this was coupled with severe wear of the journal. In the case of other alloys no appreciable wear was noticed. The journal was also free from any visual damage. From the comparative density figures of these bearing alloys it would no doubt appear that for a given weight of metal, the number of castings obtainable from alloy 1 would be three times that from a tin bronze. For alloy 2 the number would be twice as much. Associated with the lower density figure the comparitively less cost of aluminium would offer a considerable amount of saving in the final cost of the material itself.

In addition to the general economy and availability of the basic raw materials, the service life, strength and corrosion resistance are the other remarkable advantages offered by these types of new bearing alloys and it is for the industry in India to change over wherever possible to conserve copper base alloys for other important uses.

Construction Metals for Chemical Plants : Indigenous Availability

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The choice of materials of construction for chemical plant and equipment is primarily dictated by factors such as corrosion resistance, strength to resist loads, and stresses and relative costs of two or more materials equally acceptable. The chemistry of the process leads to evaluation of the chemical resistance and the operating conditions such as pressure and temperature define the limits wherein relative inertness of the material of construction must be achieved. While it is essential that the materials do not corrode, it is likewise necessary that no material pick up occurs. The latter is particularly true when minute quantities of metal taken from the equipment might cause undesirable catalytic effects.

Materials for chemical plant construction fall into two general classes, metals and non-metals, the former class being divisible into pure metals and alloys. Quantitatively probably the metallic materials from the bulk of the usage although non-metallic materials such as wood, stoneware, glass, plastics etc. find application depending on specific corrosion resistance characteristics. Of the metals the ferrous, i.e. iron and its alloys is in predominant usage because of their relative inertness, lower cost and fabrication ease. Non-ferrous metals such as copper, aluminium and their alloys are usually more expensive and are used where ferrous metals cannot be applied from the standpoint of corrosion or product contamination. Constructional metals for the fabrication of chemical process vessels are used in the form of sheets and plates, pipes and tubes, castings and forgings. Good practice and standard codes of design and construction call for use of materials to appropriate specifications and with minimum requirement of mill certificates or other proof of quality.

This note intends to outline or refer to the specifications of some of the important materials called for in overseas codes of construction such as British Standard 1500 : 1958—'Fusion Welded Pressure Vessels for use in the Chemical Petroleum and Allied Industries'—and ASME Boiler and Pressure Vessel Code Section VIII, the nearest Indian Standards available, current conditions of availability of materials conforming to the latter and suggestions on alternative indigenously available materials for certain applications and on modified methods of construction to conserve imported materials. Though the design and construction of steam boilers is subject to Indian Boiler Regulations, 1950, an Indian Standard for Unfired Pressure Vessels is still in the course of preparation. Current indigenous design and fabrication is therefore generally based on BS. 1500 : 1958 or ASME Section VIII subject to local limitations.

Carbon and low alloy steels

Iron and its alloys account for the bulk of the metals used in chemical plant and equipment manufacture. The three general groups of ferrous metals are cast iron, wrought iron and steels. Plain carbon steels also commonly referred to as mild steel may contain as much as 1.25 per cent manganese, 0.20 per cent silicon and small amounts of various other elements. The alloying element controlling its characteristics is carbon. List of ASME approved specifications for carbon steel and low alloy steels and also those permitted by BS. 1500 – 1958 are given below:

As per ASME Boiler & Pressure Vessel Code — Section VIII

SA-7 — Steels for Bridges and Buildings

SA-113 — Structural Steels for Locomotives and Cars

SA-283 — Low and Intermediate Tensile Strength Carbon Steel Plates of Structural Quality

SA-30 — Boiler and Fire Box Steel for Locomotives

SA-129 — Open Hearth Iron Plates of Flanged Quality

SA-201 — Carbon Silicon Steel Plates of Intermediate Tensile Ranges

SA-212 — High Tensile Strength Carbon Steel Plates

SA-285 — Low and Intermediate Tensile Strength Carbon Steel Plates of Flanged and Fire Box Qualities

SA-299 — Carbon Manganese Silicon Steel Plates

SA-414 — Carbon Steel Sheets of Flanged and Fire Box Qualities

SA-433 — Leaded Carbon Steel Plates of Flanged and Fire Box Qualities

SA-202 — Chrome Manganese Silicon (CMS) Alloy Steel Plates

SA-203 — Nickel Steel Plates

SA-204 — Molybdenum Steel Plates

SA-225 — Manganese-Vanadium Steel Plates

SA-302 — Manganese Molybdenum Steel Plates

SA-357 — 5% Chromium, 0.5% Molybdenum Steel Plates

SA-387 — Chromium Molybdenum Steel Plates

SA-410 — Chromium-Copper-Nickel, Aluminium Alloy Steel Plates

As per BS. 1500-1958

BS. 1501-101 : 1958 — Carbon Steel

BS. 1501-151 : 1964 — Carbon Steel (Semi killed)

BS. 1501-161 : 1964 — Carbon Steel (Silicon killed)

BS. 1501-211 : 1964 — Carbon Manganese Steel (Semi killed)

BS. 1501-213 : 1964 — Carbon Manganese Steel (Semi killed) Niobium Treated

BS. 1501-221 : 1964 — Carbon Manganese Steel (Silicon killed)

BS. 1501-22 : 1964 — Carbon Manganese Steel (Silicon killed) Aluminium Treated

BS. 1501-240 : 1958 — Carbon Molybdenum Steel

ASME SA-7, 113 and 283 and BS. 1501-101 : 1958 steels are of the structural category and are permitted only for pressure vessels of light

construction. The nearest equivalent indigenous material to that is IS : 226-1962 — 'Structural Steel (Standard Quality)' and IS : 2062-1962 'Structural Steel Fusion Welding Qualsty'. The only available Indian Standards of Steel plates for boilers and pressure vessels are IS : 2002-1962 ' Steel Plates for Boilers ' and IS : 2041-1962 — ' Steel Plates for Pressure Vessels'. The latter specifies two types, one of the modybdenum bearing and the other a manganese steel. It is, however, believed that as normal production from the steel mills only plate material to IS : 2002-1962 is available. Any other specifications steel as called for by codes, the steel plants might agree to manufacture against specific orders if the quantity warrants but obviously delivery will be prolonged. Since April, 1965 the ISI Certification Scheme to check production of certain specifications of steel has been in operation in the steel plants. At the moment this scheme covers only IS : 226-1962 and IS : 2062-1962, which are of interest to chemical plant fabricators though limited in extent and the scheme would probably be extended gradually to include additional grades such as Boiler Plates to IS : 2002-1962. The necessity of such extension of the ISI Steel Certification Mark Scheme would need hardly any emphasis as only such a procedure can improve the availability of steel to approved specifications for the chemical plant fabricators through normal trade channels. Indigenous capacity for manufacture of steel plates though available up to 63 mm thickness, material above probably 40 mm in thickness is hard to get. Despite the country's increased steel production, availability of steel through normal trade channels duly supported by mill certificates continues to be difficult except in the case of direct bulk orders on mills. This is not always possible having regard to the minimum tonnage per thickness called for by mills and to the limitations in the off-take of the fabricators in different thicknesses. It would be of much assistance to the chemical plant fabricating industry if the steel mills could make available through their stock-yards material to approved specifications. It is appreciated that stocks in every category and thickness cannot be carried always and perhaps by mutual arrangement between the consumers and the suppliers, stocks could be carried of specified categories in thicknesses of common usage.

List of ASME approved specifications for carbon and low alloy steel castings and those as per BS. 1500-1958 are given below :

As per ASME Approved Specifications :

SA-216 — Carbon Steel Castings Suitable for Fusion Welding for High Temperature Service

SA-217 — Alloy Steel Castings for Pressure Containing Parts Suitable for High Temperature Service

SA-352 — Ferratic Steel Castings for Pressure Containing Parts Suitable for Low Temperature Service

As per BS. 1500-1958 :

BS. 1504-101 — Carbon Steel Castings (Structural Purposes)

BS. 1504-161 — Carbon Steel Castings (for Parts under Pressure)

BS. 1504-240 — Carbon Molybdenum Steel Castings

Available Indian Standards for steel castings are :

IS : 2858-1964 — Carbon Steel Castings Suitabl for High Temperature Service (Fusion Welding Quality)

IS : 503-1963 — Steel Castings Alloy Austenitic Manganese

IS : 2644-1964 — Steel Castings High Tensile

IS : 2708-1964 — Steel Castings Manganese 1.5%

IS : 276 -1963 — Steel Castings Plain Austenitic Manganese

While there are many foundries, facility and capacity to produce castings to approved specifications and compositions are limited to a few with resultant difficulties in the easy availability of steel castings. The situation is similar with steel forgings as well. The available Indian Standards for forgings are :

IS : 2004-1962 — Carbon Steel Forgings for General Engineering Purposes

IS : 2611-1964 — Carbon Chrominm Molybdenum Steel Forgings for High Temperature Service.

ASME Section VIII and BS. 1500-1958 stipulate pipes and tubes in carbon and low alloy steels to various specifications related to service. The available Indian Standards for steel tubes and pipes as far as chemical plant fabrication is concerned are : 1914-1961—'Boiler and Super Heater Tubes', 2416-1963 — 'Boiler and Super Heater Tubes for Marine and Naval Purposes' and 1200-1964 — 'Mild Steel Tubes and Tubulars'.

Though in the organized sector there are in all about nine producers, only two of these manufacture pressure tubing. Bulk of the indigenous tube production is of the low pressure category suitable for water and air service in this range. Electrical resistance welded as well as seamless steel tubes are produced in the country. The indigenous supply, however, falls short of demand necessitating import. Current deliveries for ERW tubes are very prolonged. Seamless tubes again under 76 mm. o'd. are available only at a delivery of the order of 15/18 months though bigger sizes are quoted at shorter deliveries. Medium and heavy mild steel tubes to IS : 1239-1964 suitable for steam services are difficult to get. Availability of forged steel flanges and pipe fittings as normal production items is difficult and necessitates manufacture to order or fabrication from plates and bars, latter procedure not always acceptable particularly for severe service.

Statistical data on industrywise break-up of requirements of steel are not readily available but guestimating on the annual value of process plant and equipment required and weighted average per tonne of fabrication, current requirements of carbon steel for chemical plant and equipment may be put at 35,000 tonnes per year. Despite the fact that this is only a small proportion, of the country's production, because of the overall short supply of steel and the chemical plant fabricating industry's need for steel to more stringent specifications, availability of appropriate material is not easy.

High alloy steels

Chromium is an important alloying metal for steel because of its capacity to develop specific characteristics either by itself or in combination with other alloying elements. Low chromium steels containing 4 to 10 per cent chromium and possibly small amounts of molybdenum, nickel, silicon etc. are more corrosion and heat resistant than similar low alloy steels and find application in oil refinery equipment, catalytic chambers, valves etc., where high temperatures are involved. Stainless steels (high chromium and chromium nickel alloys of iron) occupy an important place in processing equipment used by chemical and allied industries. These

are durable, heat and corrosion resistant, non-contaminating. They are also easily fashioned and maintained. There are more than 30 standard types of stainless steel and many special alloys. They all contain at least 12 per cent chromium, often 7 per cent or more nickel sometimes molybdenum, columbium, titanium and other additives. The straight chromium stainless steels have less corrosion resistance than the chromium nickel grades. Therefore the 18 per cent chromium, 8 per cent nickel stainless steels are the ones predominantly applied for chemical plant construction. Even among the 18/8 categories, those with added molybdenum in general possess superior corrosion resistance. The well-known types of chromium nickel stainless steels, referring by AISI Nos. are 304, 304L, 321,347, 316 and 316L. The last two types are of the molybdenum grade and the suffix 'L' is indicative of low carbon content. Type 321 and 347 incorporate stabilising elements titanium and columbium to prevent carbide precipitation during welding or stress relieving. Carbide precipitation can also be prevented by keeping the carbon content at low levels and hence the advent of the low carbon austenitic chromium nickel stainless steels having 0.03 per cent maximum carbon.

Stainless steel requirement for chemical process vessels and plant fabrication is estimated approximately 5,000 tonnes per year and all stainless steel, whether in the form of sheets, bars, or rods, plates or tubes, are at the moment imported there being no indigenous production. Stainless steel castings are produced in very small quantities. The Durgapur Alloy Steel Project contemplates manufacture of stainless steels but it might be another 2/3 years for its production to be available to the chemical plant fabrication industry.

Cast iron

There is adeqaute indigenous capacity to meet the requirements of grey iron castings by the chemical plant fabricating industry. The annual capacity available for grey iron castings at the beginning of the Third Plan was of the order of 12 lakh tonnes including the organized and small scale sectors. Still sound castings for lack of quality control are available only from limited sources. Cast iron pipes which are generally used only for light duties and/or where it offers better service from the standpoint of corrosion resistance are produced in the country.

Aluminium and its alloys

Aluminium has long been recognised as an excellent metal for chemical containers and processing equipment. The advantages of aluminium and its alloys are light weight, ease of fabrication, high reflectivity, non-sparking quality and corrosion resistance. Aluminium has been found particularly desirable in the manufacturing and handling of nitrogen solutions. Aluminium is unaffected by atmospheric contaminants present in most plant areas. It usually does not require protective coating. Of prime importance is the added advantage offered by the fact that aluminium salts are non-toxic and colourless.

Aluminium and its alloys finding application in chemical process equipments fall into three main categories—the pure, the manganese and magnesium alloys. The ASME specifications governing this is SB-209 and the British Standards 1470 to 1477 : 1955. The relevant Indian Standards are IS : 736 and 738 : 1956 for plate and tube respectively and 737 : 1955 for sheet and strip. The designations in the Indian Standard

are more or less on the lines of British Standards. There are also the heat and non-heat treatable varieties. The corrosion resistance in general is higher the purer the metal or alloy; on the other hand the strength decreases.

Aluminium up to 99.7 per cent purity and the manganese and magnesium alloys are indigenously produced. The country's aggregate requirement is over 100,000 tons per annum and the chemical plant fabricating industry's share of this will probably be only about 5,000 tons. The current indigenous production is in the vicinity of 55,000 tons per annum shared by 4 manufacturers. Obviously next to iron and steel the county is most favourably placed with regard to aluminium from the standpoint of indigenous raw material resources and manufacture. Still the indigenous availability cannot be considered easy because of the gap in requirement and production and the priority for certain requirements which help to reduce the pressure on more scarce materials such as copper and its alloys. Extruded aluminium tubing is made locally but seamless category needs import from abroad as also plates above 25 mm. thickness.

Copper and its alloys

Copper and its alloys have inherently good resistance to corrosion and also have the property of forming films of insoluble corrosion products in many environments so that effective corrosion protection results. Copper and its alloys because of their malleability afford fabrication ease. Brasses are basically copper-zinc alloys and bronze copper-tin ones. For construction of vessels and towers mainly copper is used and with present day preference for welded fabrication, copper of the deoxidized variety is essential for production of sound welds. Copper alloys mainly find application in heat exchangers as tubes and tube plates.

The ASME Specification for copper sheet, strip, plate and rolled bar is SB. 152-60 and for copper, copper alloy seamless condenser tubes and ferrule stock SB. 152-60. The British Standards in this respect are BS. 1172-74 ‘ Raw Copper ’, 839 : 1961 ‘ Rolled Copper ’, 378 : 1963 ‘ Solid drawn copper and copper alloy tubes for condensers, evaporators, heaters and coolers’ and 1464 : 1957 ‘ Solid drawn copper alloy tubes for heat exehange equipment in the petroleum industry ’. The available relevant Indian Standards are 191 : 1958 ‘ Copper ’, 1972 : 1961 ‘ Copper plate, sheet and stripts for industrial purposes ’ and 2371 : 1963 ‘ Solid drawn copper alloy tubes for condensers, evaporators, heaters and coolers using saline and hard water’. As regards code of design and construction for copper plant that of ASME is the comprehensive one available.

Indigenous production of virgin copper and that too only of the commercial and electrolytic grades is confined to one firm and meets only a small part of the country's requirements, less than 10 per cent. Deoxidized weldable grade copper is again manufactured by only one firm utilizing imported ingots. Copper and brass of indigenous make are available as sheets and plates as also tubes but materials supplied to acceptable specifications are at times not up to the mark emphasizing the need for better quality control during manufacture. Indigenous facilities can roll plates only up to 15 mm. thick or so and tubing up to 75 mm. size. Copper and copper alloys along with zinc, lead and tin are now scarce because of restricted imports caused by limitations in availability of foreign exchange.

Lead, tin and zinc

Lead is unique and an important constructional material for the chemical process industries because of its high corrosion resistance to weather, soil, salt water, many chemicals and in particular sulphuric, phosphoric and chromic acids. In addition lead is relatively inexpensive and readily salvageable. It is extremely durable, pliable and malleable. Because of its low strength and creep characteristics it is used mostly as a coating or lining even when highly alloyed with hardening elements.

Tin is very malleable and when pure, extremely resistant to corrosion. As a coating it is used to protect iron and also as a lining in copper vessels when contamination by latter is not permissible. Zinc again is used as coating or as an alloy with copper.

Though indigenous facilities exist for the rolling of lead sheets and pipes, manufacture is primarily based on imported virgin metal, indigenous production being to the extent of less than 10 per cent of the requirements. Zinc and tin as it stands are totally imported.

Nickel and its alloys, titanium and other special alloys

Nickel is an excellent corrosion resistor for atmospheric conditions, salt water, neutral and alkaline salt solutions and alkalies. Its mechanical properties are excellent and thus it is a preferred material for plant construction when its high price can be justified. Monel, the familiar nickel copper alloy, is composed of approximately two-thirds nickel and one-third copper. In view of the fact that both nickel and copper possess considerable separate and different kinds of resistance to chemical attack, it is not surprising that monel possesses a useful degree of resistance towards corrosion than any other malleable metal. Inconel containing approximately 77 per cent nickel, 15 per cent chromium and the balance iron, besides its resistance to corrosion, is a high temperature service alloy.

Titanium and tantalum are recent entrants in the chemical plant construction field and both are expensive. While the primary incentive to commercial development of titanium arose from its unique strength to weight ratio and the exploitation of this in aircraft construction, its excellent resistance to metallic chlorides, organic acids and oxidizing inorganic acids, wet chlorine, chlorine bleaching derivatives over a wide range of temperature and concentration has made possible its increasing use as a constructional material in various process plants. Tantalum is equally known for its almost immunity to corrosion or chemical attack in environments involving chlorine and its compounds including hydrochloric acid or substances containing chlorides or hydrochloric acid. Even boiling aqua regia does not attack tantalum.

As regards the above materials there is no indigenous source or production and dependance on imports is inevitable. Titanium and tantalum application in the present stage of industrial development is very limited.

Import substitution

It is obvious from the above review that in the case of no constructional metal barring probably grey cast iron, indigenous requirements are fully met locally. Substitution for imported metals can therefore only be relative in nature. The only three really indigenous materials available are cast

iron, carbon steel and aluminium. Any possible reduction in import has to be through increased use of these materials by way of partial or total replacement. Here again having regard to the special requirements of chemical process equipmeni, in particular, from the standpoint of corrosion resistance and process/product contamination, there are limitations. However, to cite a few the following might be considered :

At the moment molasses based alcohol plants employ mainly copper as material of construction for the columns, condensers and piping in the distillation section. Particularly when the end use of alcohol is for industrial purposes, copper could be substituted by steel construction except probably in the case of the wash or analysing column which handles acidic fermented wash.

Corrosion resistant steel linings are worth considering where it is wished to retain the corrosion resisting advantages of solid corrosion resistant steel or other special metals. The lining can either take the form of close fitting sheet material or integrally bonded claddings. The latter is again ruled out as import will be necessitated. Sprayed coatings because of the porosity of the deposited metal is not always satisfactory. When heat transfer through the metal wall is involved, sheet lining could adversely affect heat transfer efficiency but a compromise is necessary somewhere. As the backing material will be steel, any lining material should be capable of being welded to steel. Overseas literature indicates that in the case of stainless steel, for construction requiring a wall thickness of 6 mm. or under it is usually more economical to make use of solid material and the lining becomes definitely economical above 16 mm. wall thickness.

In shell and tube exchangers of stainless steel and other special metals construction, where the tube side governs corrosion resistance, steel tube plates with sheet lining on the header side can assist in saving imported thick alloy tube plate material.

What we do on Aluminium to Replace Non-ferrous Metals

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In a vast country like India, natural resources for various metals should be abundant. But till recently very little has been explored. As it stands now, Indian resources for such non-ferrous metals as copper, nickel, lead, zinc and tin are very scanty and she has to depend mainly on imports. Ores containing aluminium, titanium, manganese, magnesium and berylium occur as thick deposits in various parts of our land. Achieving self-sufficiency in the production of these metals appears to be impossible as the demands for these metals are increasing year after year in India, because of the industrial map of India expanding under the tempo of her Five-Year Plans.

One method of overcoming this difficulty to conserve foreign exchange is to explore the scope and potentialities of substitutional metals available in India (in the technological, engineering and other fields) for these non-ferrous metals in which India is very poor. Any research in this direction has therefore to be oriented in such a way as to investigate scientifically the utilization of substitutional metals and establish their acceptance by industrialists.

The one metal which meets all these requirements that is which can be used as a substitutional metal in place of copper, tin, lead and zinc and for which resources in India are so abundant that self-sufficiency can be expected to be achieved is aluminium. The present estimated resources of bauxite, the chief ore for aluminium production, are more than 250 million tonnes and the estimated capacity of aluminium production in India is 142,500 tonnes by 1970. This Institute is quite alive to this problem and is taking up investigation on utilization of aluminium so as to discourage use of copper, zinc etc., and thus help in its own way to reduce substantially the drain on foreign exchange reserves.

The present report is a broad outline of the work done or envisaged to be taken up in the Metal Finishing Section of the Institute on aluminium to establish its importance and to increase its popularity particularly in the background of Indian conditions.

Aluminium electrolytic capacitors

There is no single electronic instrument which does not employ at least one capacitor in its circuit. Of different types of capacitors, the electrolytic capacitors stand foremost in application because of their compactness higher capacity and favourable economic factors.

The electrolytic capacitor industry in India is fast growing. The estimated licensed capacity for the production of electrolytic aluminium capacitors is expected to be 20 million pieces annually and may go up every year. A few firms in India have gone into production of these capacitors with foreign collaboration in setting up of the plant and getting the know-how at a heavy cost.

This Institute has done much work on aluminium electrolytic capacitors and the process has been given to M/s Resa Radios, Madras. The etching of both super purity aluminium[1] and commercial purity aluminium for use in low voltage capacitors has been investigated to achieve maximum electrical magnification by using a periodic reversal current and the etch ratio has been increased from 8–9 obtained by conventional methods to 12–14 by the new technique[2]. Etching of aluminium for use in high voltage capacitors is usually done with a.c. superimposed d.c. and the machinery is rather costly and has to be imported. This Institute has worked a process[2] which can get a fairly good etch ratio using d.c. thus eleminating the use of complicated and costly machinery. The optimum conditions for obtaining anodic oxide dielectric films on these etched surfaces has also been studied in detail. It is also proposed to set up a small continuous etching and forming unit to work out the conditions for the fabrication of high voltage type capacitors.

The present production of capacitors has reached only 50 per cent of the estimated production. Hence the further setting up of units for production of capacitors may be done with the know-how developed here.

New type of aluminium oxide dry capacitor

This type of capacitor developed quite recently in some of the advanced countries combines the best properties of the conventional electrolytic capacitor and also those of the high stability paper varieties. The oxide is is the dielectric as the case with conventional electrolytic capacitor but the main difference lies in that the counter electrode is aluminium itself deposited by vacuum coating and no liquid electrolyte is employed. This obviates the difficulty usually met with electrolytic capacitor where the properties of the electrolyte changes and in turn the electrical characteristics of the capacitor when operated at low temperatures. Work on this type of capacitor has been taken up and the preliminary results are encouraging.

Hard anodizing

One of the versatile qualities of aluminium is the formation of an oxide coating on the surface which when favoured by proper choice of conditions can be made harder than steel. Thus the light weight of aluminium combined with the hard wear resistant surface coating of an oxide film has immense potentialities in the engineering applications, transportation industries (Rail, Coaches etc.), aircraft appliances, automobiles, accessories for automatic computers etc.

A suitable bath composition has been worked out in this Institute based on oxalic acid-sulphuric acid electrolyte[3–6]. The optimum conditions are 5 to 10°C. at a current density of 36 asf. in the above electrolyte..

One of the major items in the economics of hard anodic coatings is the heavy cost of refrigeration required to control the bath at such a low

temperature. Further investigations are being carried out at this Institute for the production of hard anodized aluminium at 20-25°C and the initial experiments show encouraging results.

Wire anodizing and strip anodizing

Considerable progress has been made in the production of anodic oxide films on aluminium by controlled anodic oxidation. The thickness can be controlled to close tolerance limits with electric insulating characteristics and such insulated films can be easily colour coded. These insulating films on aluminium are now produced by continuous wire anodizing[6]. Because of their compactness, good stability at high temperature, ease of fabrication they can replace other types of insulated wires on aluminium. The anodized wires find use in transformer windings, woven wire clothes etc. This Institute has a programme of research for continuous wire and strip anodizing.

Decorative anodizing

The rapid advancement of aluminium industry over others is as already stated, due to its many versatile characteristics and adaptability to varied applications. One such is the flexibility of the characteristics of the oxide film. The oxide film can be thickened and made sufficiently porous to absorb dyes, sensitizing emulsions, ink etc. by proper choice of anodizing baths under suitable operating conditions. Processes have been worked out in this laboratory for anodizing[7], colouring[8–10], photographic reproduction[11], and multicoloured effects[12], which find ready application in decorative art such as thermos flask covers, cans, name plates[13], dials, scales, window frames, architectural work[14] etc. Such anodized and dyed specimens are replacing steel, brass and copper parts in many fields. The net savings that can be effected run up to several lakhs of rupees apart from imparting pleasing aesthetic taste.

The spangled appearance of galvanized sheets is beautiful and appealing in its own way. Such a spangled surface finish could be produced on certain aluminium alloys, by controlled heat treatment and this effect can be further enhanced by anodizing and dyeing. The industry is fast developing in Japan. The know-how of this process to produce multi-toned effects on aluminium articles of fancy have been completed by this laboratory and the results are ready for emploitation.

Electropolishing and chemical polishing

The electropolished and anodised aluminium reflectors are found to be the best from the view point of retention of reflectivity, resistance to tarnish, light weight, durability and cheapness compared to other plated reflectors which are now in common use[15]. The heat lights of locomotives, automobiles, the reflectors in torch light, projectors etc. can be completely replaced by electropolished and anodized aluminium reflectors. This Institute has worked out the know-how of all the polishing processes for electropolishing of aluminium and aluminimum alloys[16–18].

A detailed study on the trisodium phosphate and sodium carbonate electrolyte has established its cheapness and advantages over the other processes. This process is ready for handing over to industries. A method for increasing the life of such electropolishing bath has also been evolved.

The advantages of chemical polishing over electropolishing in certain types of applications is well known. The chemical polishing methods have also been investigated in this laboratory and can find application in fancy goods industries such as imitation gold, fountain pen caps, costume, jewellery and the like.

Electroplating : black chrome and nickel on aluminium

Black metallic surface finish with sufficient hardness and abrasion resistance is utilized in manufacture of scientific instruments, camera industry and some specialized applications. The cartridge cases in the military is made of steel and given a black coating by phosphating. In this field alone the advantages of using aluminium instead of steel can be easily appreciated because of its lightness. The lessening of the load of the equipments a soldier has to carry on him cannot but be appreciated and approved even if the cost is slightly high. But if one can achieve the same result at competitive rates with better service conditions it will be a boon. One such a field is the use of black chromed or black nickeled aluminium in place of steel. It would therefore be highly appreciated, if the industry is persuaded to take up this work immediately. Towards this aim in view, know-how for the processes for black chromium plating[19], and black nickel plating of aluminium[20] have been investigated in this laboratory and established to be applicable.

Electroplating : Direct copper on aluminium

Electroplating on aluminium[21] has been carried out with the main objective of combining the light weight and economic aspects of aluminium with the special surface properties of the coated metal required in any particular field of application. One particular field where direct deposition of copper on aluminium has immense potentialities is in the production of bimetallic plates for the printing industry.

The conventional procedures for plating nickel, chromium, silver or other metals on aluminium are the zincate process and the phosphate anodizing process. The former process involves a critical control of zincate treatment depending on the alloys of aluminium used and a long plating schedule. The latter process suffers from the main disadvantage of cost of production being high.

A new process is being investigated in this Institute to deposit copper directly on aluminium[22]. The literature on direct plating of acceptable deposit of copper on aluminium is scanty and almost all the baths use tri-, di- or monoethanol amines. The bath that is developed here is non-toxic, cheap and does not contain the amines mentioned above. The raw materials required for make up of the above bath is readily available in India. The deposit obtained is very bright, smooth, adherent and is obtained at very high current efficiency. No special treatment is necessary for different alloys of aluminium plating on 2S, 3S, 26S, 57S and 65S alloys. All of tl em gave very bright dense adherene deposits with the same pre-plating treatment.

The copper, brass and bronze utensils now popular in India are on the decline because of shortage of copper, zinc and tin. During the last 15 years aluminium household appliances and utensils are gaining popularity and is expected to capture the entire market by 1970. The consumption will go up to 35,000 tons annually. Naturally the exploita-

tion on aluminium for decorative metalware will be increased if a cheap, easy and elegant method for depositing metals directly on aluminium is made available to the Industry. Direct plating of copper on aluminium then not only serves to replace copper in this important field but has direct application in the production of bi- and trimetallic printing plates as mentioned earlier.

The term bimetallic plates refers to a plate in which the printing and the non-printing areas are composed of different metals. The printing metal is always copper since it is very easily made ink receptive. The non-printing metal is usually chromium, stainless steel or aluminium which are easily desensitized to ink. One type of bimetal plate consists of stainless steel or aluminium plate electrodeposited with a thin layer of copper. The possibility of depositing stainless steel on aluminium is being explored recently.

Electrophoretic deposition of aluminium

Electrophoretic deposition has got various advantages over other methods of coating. Mention may be made of the high corrosion resistance ductility, control of thickness, high efficiency and economy.

Preliminary studies on the electrophoretic deposition of aluminium powder on mild steel has been made from various non-aqueous media. Conditions for getting uniformly thick deposits of aluminium powder on mildsteel sheets have been standardized. Further work to improve corrosion resistance of the coating is in progress.

Stainless steel plated aluminium

Stainless steel plated aluminium has potential uses in the manufacture of vessels especially kitchen utensils. It is cheap and is easy to clean and the corrosion products are not poisonous. Work on this has been taken up recently and the preliminary results are encouraging.

Lithographic plates

The special advantage of lithographic printing technique is well established and 50 per cent of the zinc strips and sheets imported in India is consumed for the lithoplates. The demand for lithographic plates was 3,000 tons in 1959, that is nearly Rs 70 lakhs had to be spent by way of foreign exchange for the import of zinc for this purpose alone. The aluminium sheets and foils are better substitutes for zinc lithoplates and anodizing processes have been developed for aluminium in a German Patent.

Because of import licence restrictions and non-availability of processes for production of lithoplates in India, the printing industry is facing a severe setback these days.

A new process for anodizing aluminium plates for litho printing has been developed in this Institute using cheap chemicals, apart from a chemical conversion coating method which has also shown some promise[23]. The process involves anodizing in an aqueous solution of potassium chromate. The method can be developed into a continuous process for cheap production. The cost of each plate (12 in. × 8 in.) works out to only 20 P. whereas it is now sold at Re 1·00 per plate. This has a great scope for industrial exploitation.

Soldering of aluminium cables

The high thermal and electrical conductivity of aluminium combined with its light weight has made its use in electrical industry technically acceptable and economically feasible. Because of this one reason alone, production of aluminium is increasing in greater rate than the population of India or the expansion of electricity generating capacity. One of the main obstacles in the use of aluminium for replacing copper is the jointing problems. Replacement of copper conductors and cables by aluminium conductors to the extent of 15,000 tons by 1970 is envisaged in Third Five-Year Plan. Hence any method which is comparable in case of application with that of jointing copper cables will be a boon to this industry. Two of these methods are soldering and 'bolting'. Peirson has reported that the work done at C.M.A. has established that soft soldering methods were most practical.

The technique of soldering of aluminium cables is rendered difficult by the presence and ready formation of the tenacious oxide film on the surface. Proper fluxes (organic and reaction types) and special solders have been developed in other countries. Little work has been done in our country in this direction. Our Institute has developed fluxes and solders for aluminium cable jointing which are well comparable to any imported types of fluxes and solders in their performance. The work is in progress to develop reaction fluxes also which have better performances in certain fields of application.

Aluminium batteries

With the development of new technology, demand for chemical sources of current has expanded considerably together with an increase in the requirements with reference to the power and specific characteristics of galvanic cells. In this connection, the possibility of using aluminium anodes in cells is attracting attention.

Aluminium has a high negative normal potential of —1·66 V. in acid solution and —2·35 V. in alkaline solution and at the same time has a low electrochemical equivalent. The calculated capacity for aluminium is 2·96 amp. hr/g. and 0·85 amp. hr/cm.^{3} compared with 0·82 amp. hr/g. and 5·85 amp. hr/cm.^{3} for zinc.

Against these advantages the choice of aluminium introduces considerable difficulties in the choice of electrolyte, corrosion of anode etc. Systematic work to solve some of these difficulties has been taken up and the results are promising.

The polarization characteristics of aluminium anodes in various electrolytes were studied over a wide range of current density and based on the results, a few electrolytes have been chosen for use in aluminium batteries. Controlled amalgamation of aluminium anodes in some electrolytes in presence of inhibitors makes it possible for use in primary cells. Primary cells using a.d. cathodes or MnO_2 cathodes and aluminium anodes are being fabricated and tested.

Single shot aluminium battery

Possibility of using aluminium anode in single shot batteries has been intensively studied and the condition under which it can be efficiently used

in place of magnesium has been established. A patent in this regard has been filed.

Enamal finishes on aluminium

In comparison with the other finishes on aluminium, there is still a definite field of application for various enamelling of aluminium especially for architectural applications, roof signs, tanks and containers, and aircraft components etc. For exterior use vitreous enamelling on aluminium provides a much wider range of colours than anodizing. Advantages of enamelled aluminium over steel are its light weight, absence of chipping, allow drilling and cutting and avoidance of ugly rust at points of local damage. The aluminium is cleaned and the enamels are applied by spraying, slushing or dipping the work in the wet slip. The firing operation is carried out in a muffle furnace at 500–550°C. for 5–10 min.

Laminated coatings of aluminium

The possibilties in this field are virtually limitless but laminates of aluminium with insulating materials are the main (immediate) interest. A typical composits panel consists of a resin bonded fibre glass between two thin sheets of aluminium. Many proprietary roofing systems utilize aluminium with insulation board and bituminous felt. The use of foamed aluminium as the sandwich filling is being increasingly adopted.

There are many advantages to be derived from the use of this light metal roofing, it will not crack or leak, it is nonrusting, and resistant to every normal corrosive conditions and it is unbreakable and noninflammable. We have a programme of research for producing such laminated coatings of aluminium.

Super purity aluminium

The need for super purity aluminium exists mostly for the manufacture of electrolytic capacitors of various specifications. The technical know-how is to be worked out. In this direction it is proposed to process as follows.

Preparation of aluminium-copper alloys starting from the scrap metals or by heating the aluminium oxide or scrap aluminium with carbon in presence of copper or copper oxide scals (obtainable from by-product industries) in electric furnaces. In the second step the copper aluminium alloy will be utilized as anode and super purity aluminium will be deposited on a cathode of super purity aluminium itself.

The experimental work is getting ready. The various compositions of the alloy, the current density, the electrolyte compositions, temperature ranges and the life of the refractories will all be assessed. Indian made refractories will be utilised for the purpose.

Alternate methods for aluminium manufacture as well as raw materials

The production of alumina, suitable for aluminium electrolysis in the conventional procedure involves the treatment of bauxite in the first step. All bauxites are not amenable to Bayer treatment. Some of the bauxites require larger quantities and high concentration of caustic soda, higher temperature and pressures for dissolving out pure alumina from bauxite.

Silicious bauxites are not amenable to this treatment. Hence a two stage process is now adopted in which the red mud containing insoluble sodium aluminium silicate is calcined with sodium carbonate at high temperature and sodium aluminate is leached out.

In countries where there is deficiency of high quality bauxite and also where fire clay and other similar aluminous materials are in abundance acid procedures for the extraction of aluminium have been adopted successfully. This method is also applicable to silicious bauxite. We have established conditions here for the extraction of aluminium from the fire clay available in Neyveli Lignite deposits by a cyclic acid process in which ammonium sulphate is used as the intermediary chemical. Thus this work is of importance as it allows cheaper raw materials to be utilized in aluminium manufacture.

The consumption of carbon anode is a serious problem in the conventional procedure for the extraction of aluminium metal. Although the normal consumption is about 0.7 ton per ton of aluminium produced in some factories, it goes up to the extent of 1 ton of carbon consumption per ton of aluminium produced. By producing chlorine as anode product, it is possible to save life of the anode. With this aim in view, we had a programme of electrolysing mixtures of sodium cryolite with sodium chloride in admixture with small quantities of alkali and other alkaline earth metal chlorides. Therefore, the first step was to produce cryolite very economically and also to investigate the conditions for making use of the effluent which will be reacted with alkali metal chlorides to get cryolite back.

We have used bauxite, purified alumina as well as clay as raw materials for the production of cryolite and established conditions for the same. Another important aspect is the utilization of hydrofluosilicic acid obtainable as a by-product in the superphosphate manufacture, for the production of cryolite as well as for the production of aluminium fluoride, pure calcium fluoride, sodium fluoride which are used as correctives for the electrolytic composition. The intermediary cryolite itself gained importance and potassium cryolite specially for defence, is being prepared by the procedure developed here. A process for the manufacture of sodium cryolite has been handed over to 9 parties and demonstrations were arranged at Guindy Industrial Estate, Madras.

For every ton of aluminium produced very often 0.1 ton of cryolite and about 0.05 ton of aluminium fluoride are required. Calcium fluoride requirements are almost equivalent to the aluminium fluoride. Hence the importance of the methods developed here for the preparations of the fluorides.

Work will be conducted to try the fluoride - chloride mixtures of aluminium, alkali and alkaline earth metals for the electrowinning of aluminium.

Some experiments were conducted to produce the aluminium silicide starting from clay in an arc furnace. The idea was to use the aluminium silicide in the second state of the process to get aluminium metal, viz. subhalide formation and decomposition. Neyveli fire-clay was tried first. Experiments are in progress

In the conventional cells, improvements have been effected in foreign countries through the use of cathode materials like zirconium boride carbid

in an admixture with titanium carbide-boride. Apart from the use of these as cathode materials in the conventional cells they also show promise of being utilized in other industries as well. It is but proper that a country like India where raw materials for the manufacture are in abundance, viz. zircon and ilmenite from the beach sands of Travancore, it is but fair that the work in this line is also taken up and linked mostly with aluminium industry. Experiments will be started with a view to producing them. The success of utilizing these cathode materials will depend to a great extent on their cost of production and hence the need for starting research work on the production of these materials.

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Production of Low-Ash and Low-Phosphorus Coals for Carbide & Ferroalloys Industries

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The demand for low-ash coke and char containing 12–14 per cent ash and less than 0.05 per cent phosphorus has been on the increase in recent years. The coke of the above specification is required for the manufacture of carbide and other ferroalloys industries. The Tariff Commission (1958) recommended that units for the manufacture of superior grade (low-ash and low-phosphorus) coke should be installed at an early date. With the growing tempo of industrialization, the demand for superior grade coke/char is likely to increase considerably in coming years. For the manufacture of this special type of coke/char, the coal should have ash of about 8 per cent and phosphorus 0.03 per cent or less.

Coals low in ash (below 8 per cent) can rarely be obtained at present by mining any of the known coal seams in India excepting those in Assam coalfields. But most of these coals are high in sulphur. The only alternative to produce low ash coal of the desired specification is to upgrade economically the currently mined coals of relatively lower ash (12 to 14 per cent). But to recover reasonable yields of clean coal in order to make the washing proposition economic, only those coals should be selected which yield comparatively larger amounts of low ash product. In making this selection, care has also to be taken to see that the ash and phosphorus of the raw coals are fairly low and that the percentage sulphur in these coals also is not high.

The coals used for the purpose can either be of the coking or of the non-coking type. For coals of the coking type, it is possible to use only the slack at 40 mm. or below which after necessary upgrading by washing can be carbonized in a conventional coke oven plant. Depending on the cleaning characteristics of the coal it may also be necessary to crush the run-of-mine coals of coking type to 13 mm. or below in size before upgrading and carbonization. In case non-coking coals are used, the lump size fractions generally of 100 to 25 mm. size should be upgraded and devolatilized in suitable carbonization plants to yield char of thedesired specification.

General scheme of washing

The production of low ash coals means separation of the raw feed coals at low relative density. With most Indian coals, low density separation invariably involves high near-gravity materials and calls for efficient and

accurate washing units to effect the separation of clean coal. For coking slacks heavy medium cyclones are the most suitable units. These cyclones normally treat the fractions above 0.5 mm. The slurry below 0.5 mm. can, however, be upgraded in flotation cells.

For upgrading lump coal (100 to 25 mm.) of non-coking type at low relative density, heavy medium separators using deep baths and stable media have to be employed to effect the separation of clean coal of the required quality.

Thus, the successful commercial exploitation of the production of the low-ash and low-phosphorus coals depends on the right selection of raw coal and on the proper choice of washing scheme, best suited to the type or types of raw coal selected. The present paper incorporates some investigations carried out at CFRI with both coking and non-coking coals from a number of sources in India to study the possibilities of preparing low-ash and low-phosphorus coals on a commercial scale.

Results of investigations

Coking coals. Some run-of-mine coals of the Jharia and Raniganj coalfields known to be comparatively lower in ash and phosphorus were tested to find out their potentialities for the production of low ash and low phosphorus clean coals of desired specifications.

Two of the coals tested were of coking type and belonged to the upper seams of Jharia coalfield while the third one was collected from the Dishergarh seam of Raniganj coalfield. The samples were initially crushed down to below 6 mm. and the cleaning possibilities of the individual coals were studied. The results of cleaning possibilities are presented in Table 1. It is to be noted, however, that while the cleaning possibilities of 6–0.42 mm. fractions was evaluated by float and sink analysis using organic liquids the beneficiation potentialities of the slurry below 0.42 mm. were studied in a flotation cell.

The results indicate that the yields of total cleans (6–0.42 mm. cleans plus flotation concentrates below 0.42 mm.) vary between 37 and 45 per cent at the clean coal ash level of 5.9 to 6.2 per cent. The sinks ranging between 55 and 63 per cent contain 17.8 to 24.4 per cent ash. These sinks in small sizes can either be used directly for power generation or re-washed for the recovery of clean coal (with 17 per cent ash) for metallurgical use and the high-ash rejects can be used for power generation. The detailed analysis of the low ash cleans recovered from the three coals are given in Table 2.

It will be observed from the analytical results in Table 2 that while it is possible to recover reasonable yields of clean coal with ash below 7 to 8 per cent (in actual washing operation there will be about 1 per cent ash error), the percentage phosphorus in these coals (considered for tests) hardly comes below 0.05 per cent.

Tests conducted with natural slacks from the Lower Karharbaree seam of Giridih Colliery, however, indicated that there are better possibilities of recovering low ash (6 to 7 per cent ash) and low phosphorus (0.2 to 0.03 per cent phosphorus) from this coal. Similar possibilities were observed also with Laikdih coals of the Barakar Measure (Raniganj coalfield).

Table 1 — Cleaning possibilities of coals crushed to below 6 mm.

(Figures are on per cent of total basis)

Colliery	Seam & section	Over-all ash %	Screen analysis: 6–0.42mm. Wt %	Screen analysis: 6–0.42mm. Ash %	Screen analysis: Below 0.42 mm. Wt %	Screen analysis: Below 0.42 mm. Ash %	Cleaning possibilities, Laboratory float & sink tests, 6–0.42 mm.: Cleans Wt %	Cleans Ash %	Sinks Wt %	Sinks Ash %	Froth flotation test below 0.42 mm.: Floats Wt %	Floats Ash %	Tailings Wt %	Tailings Ash %	Total cleans (plus 0.42 mm. cleans,—below 0.42 mm.floats) Wt %	Total cleans Ash %	Total sink (plus 0.42 mm. sinks, below 0.42 mm. tailings) Wt %	Total sink Ash %
Sitalpur	Dishergarh	16.2	88.8	15.8	11.2	19.2	35.0	6.0	53.8	22.2	1.8	9.5	9.4	21.1	36.8	6.2	63.2	22.0
S.B. Kendwadih	XVI	16.2	86.8	17.0	13.2	10.8	37.8	6.0	49.0	25.5	6.6	5.3	6.6	16.3	44.4	5.9	55.9	24.4
Burragarh	XV	12.5	87.0	12.6	13.0	11.5	38.1	6.0	48.9	17.8	7.3	6.7	5.7	17.7	45.4	6.1	54.6	17.8

Table 2 — Analysis of cleaned fractions (air-dried basis)

	Kendwadih XVI seam	Burragarh XV seam	Sitalpur-Dishergarh seam
Moisture,%	1·2	1·6	2·1
Ash,%	5·9	6·1	6·2
V.M.,%	30·5	28·1	39·7
Fixed carbon,%	62·7	64·1	52·0
Sulphur,%	0·7	0·6	0·4
Phosphorus,%	0·08	0·05	0·06
Caking index	34	24	24

Non-coking coals

There are good indications that some of the coal seams of Madhya Pradesh and Orissa coalfields producing non-coking coals can be potenial resources of low-ash and low-phosphorus coals. Coals included here are from the bottom seam of Talchir coalfield and from several other seams of Chirimiri, Sohagpur, Korba and Pench Valley areas.

The physical and chemicals survey of seams has shown that most of the coals from the above regions excepting those from the Kanhan Valley and a few others are low in phosphorus.

For most of these non-coking coals the washing possibilities have been considered for the lump coals in size-ranges 100–25 mm. (or 75–25mm.). On washing, these lump coals in the specific gravity range between 1.26 and 1.35, about 40 to 60 per cent or more coal can be obtained having nearly 7 to 9 per cent ash and less than 0.01 per cent phosphorus. In order to obtain clean coal with ash below 8 per cent some amount of yield has to be sacrificed in the washing process.

The cleaning possibilities of some of these coals together with the analysis of raw coal in respect of ash, moisture and phosphorus contents are presented in Table 3.

The clean coal obtained by the washing of raw sized coal can be carbonized at medium temperature to yield low volatile char of the desired chemical and physical properties. For medium temperature carbonization the chain-grate devolatilizer or retort carboniztion unit can be used. The Industrial Development Corporation of Orissa propose to produce low ash, low-phosphorus char by carbonizing in an externally heated retort the cleans (100–25mm.) obtained from the beneficiation of Talchir bottom seam coals.

Conclusion

On the basis of investigation undertaken at the Central Fuel Research Institute on the possibilities of using Talchir seam coals for the production of low-ash and low-phosphorus coke, the Industrial Development Corporation of Orissa initiated detailed investigations to explore the possibilities of preparing low ash, low phosphorus and reactive coke (char) for the

Table 3 — Some test results of non-coking coals

Source	Analysis of raw coal			Cleaning possibilities of plus 25 mm. fraction				
	Moisture(%) at 60% RH & 40°C.	Ash,%	Phosphorus,%	Density of cut	Cleans		Sinks	
					Yield,%	Ash %	Yield,%	Ash,%
1. No. 4 seam, Chirimiri Chirmiri coalfield, M.P.	6.0	14.0	0.003	1.35	58.3	9.3	41.7	21.0
2. Main seam, West Chirimiri Chirimiri coalfield, M.P.	5.2	12.2	0.003	1.35	71.0	7.9	29.0	17.2
3. Gorhela seam Duman Hill, Chirimiri coalfield.	6.4	15.0	0.003	1.35	82.3	8.7	17.7	35.1
4. No. 3 seam, Rowanwara, Pench Valley coalfield, M.P.	7.5	16.3	0.005	1.30	48.9	9.5	51.1	25.4
5. Talchir bottom seam, Handu-Duha Colliery, Talchir coalfield, Orrissa	8.4–10.8	9.2–11.6	0.003–0.009	1.25	42.8	6.3	57.2	13.1

manufacture of ferro-chrome in the Orissa State by utilizing the Talchir coals which are already relatively lower in ash and phosphorus.

Similarly, one lot of low-ash and low-phosphorus coke was prepared by CFRI for M/s Birla Brothers with a view to assessing the possibilities of their use in calcium carbide manufacture. Although encouraging results were reported, the project has not been seriously pursued up till now as low ash coals are not readily available in the market.

Thus, cleaned coal of the required quality either of coking or non-coking type when carbonized in an appropriate plant will yield coke or char that can be successfully used for the manufacture of both calcium carbide and ferroalloys.

Industrial Semi-cokes from Orissa Coal For use in Low-shaft Furnace

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The reserves of good quality iron ore in India are quite extensive (22,000 million tonnes) and their occurrences are well scattered over the country but the growth of iron and steel industry is greatly handicapped on account of the limited reserves and availability of suitable coking coals. The annual per capita steel consumption in India will be less than about 50 lb. even after the Fourth Plan period whereas in other industrialized countries it is more than 150 lb. per head at present. By utilizing the huge deposits of low rank coals (over 100,000 million tonnes) will spread out in the country, the production of pig iron can be substantially increased without drawing on the resources of coking coals. The low rank non-caking to weakly caking coals (even of low grades sometimes) on low and / or medium temperature carbonization yield semi-cokes which can be utilized in low shaft furnaces for manufacture of pig iron as well as for other metallurgical purposes.

Vast deposits of low rank coals occur in abundance in the State of Orissa[1]. The *in situ* reserves of coals is about 30,000 million tonnes.

In order to assess the low and medium temperature carbonization potentialities of these coals for production of suitable semi-cokes, bulk samples of these coals were tested in the Prototype L.T.C. Plant at the CFRI both on behalf of private as well as public undertakings.

The coals tested were mainly from Talchir coalfield. In order to use the semi-cokes in low shaft furnaces and for other metallurgical uses such as production of ferro-chrome, ferro-silicon, etc., these should have low ash, low sulphur and low phosphorus contents. The ash percentage of these coals being slightly higher than desirable. These coals were washed under different conditions in the Coal Washing Plant at the CFRI to obtain ash content ranging between 10 and 13 per cent (with $\pm$ 1 tolerance). Studies on unwashed Talchir coals were also carried out. The results of the investigations are briefly given in Tables 1 to 5.

L.T.C. plant at CFRI

The Prototype L.T.C. Plant at the Central Fuel Research Institute consists of two externally heated downward type narrow continuous vertical retorts, each with a daily coal throughput of 10 tonnes[2,3]. Full facilities are available for the recovery of by-products. The coal is charged at the top and semi-coke is discharged continuously at the bottom where the semi-coke is quenched by means of steam in the coke

Table 1 — Properties of Orissa test coals

Proximate analysis (%) (as received)	M	Ash	V.M.	C.I.	C.V. (B.t.u./lb.)
Unwashed coal	3.5–10.3	10.5–12.3	35.0–38.0	<3	11,620–12,500
Washed coal (I)	9.2– 9.7	9.8–11.0	36.0–38.0	<3	11,520–11,660
Washed coal (II)	4.7–10.7	12.4–13.7	33.6–35.2	<3	11,410

Ultimate analysis, % (as received)	C	H	S
Unwashed coal	67–69 (80–83)*	4.5–4.8 (5.4–5.8)	0.51–0.56 (0.61–0.67)
Washed coal (I)	65–66 (82.1-82.3)	4.3–4.5 (5.6–5.8)	0.54 (0.68–0.69)
Washed coal (II)	64.2 (79.4)	4.3 (5.3)	0.42 (0.52)

*Figures in parentheses indicate results in D.M.F. basis

Table 2 — Yields of carbonization products obtained per tonne of coal as charge

	Semi-coke (tonne)	Tar (gal.)	Gas (cu.ft)
Unwashed coal	0.63	19.3	12,750
Washed coal (I)	0.56–0.59	18.0–18.6	8,200–9,045
Washed coal (II)	0.57	16.0	10,600

Table 3 — Properties of semi-cokes

	Unwashed	Washed (I)	Washed (II)
(a) Screen analysis, cu. m. %			
+ 1 in.	67	62	54
+ 1/2 in.	90	86	83
(b) Bulk density, lb./cu. ft	32	32	37
(c) C.A.B. value, cu. ft./min.	0.0176	0.018	0.016
(d) Ignition point, °C.	310	320	275
(e) F.R.S. CO_2 reactivity value	190	190	188
(f) Ash fusion characteristics Hemispherical temperature, °C.	>1400	>1400	>1400
(g) Shatter values, cu. m.%			
+ 1 in.	78	72	68
+ 1/2 in.	94	92	89
(h) Micum values, cu. m.%			
+ 20 mm.	72	62	48
+ 10 mm.	83	77	72

Table 4 — Composition of gas

(Per cent vol./vol.)

	Unwashed coal	Washed coal (I)	Washed coal (II)
CO_2	3.6	7.0	5.4
C_nH_m	1.8	2.5	1.6
O_2	0.6	0.3	0.4
CO	19.0	14.0	20.0
H_2	49.0	43.5	47.5
CH_4	19.5	29.1	21.0
N_2	6.5	3.6	4.1
Calorific value, B.t.u./lb.	450	525	460
Density, lb./cu. ft	0.038	0.038	0.036

Table 5 — Gas production, consumption and surplus

(Therms per tonne of coal charged)

	Unwashed coal	Washed coal (I)	Washed coal (II)
Gas production	57	46	48.7
Gas consumption	42	25	32
Gas surplus	15	21	16·7

chamber. Provision also exists in one of the retorts to inject a suitable carrier gas for quenching the semi-coke. This gas quenching process is covered by an Indian Patent (No. 68680).

Properties of Orissa test coals

The physical and chemical properties of Orissa coals tested are presented in Table 1. On as-received basis the percentages of moisture and ash of these coals ranged from 3.5 to 10.3 and 9.8 to 13.7 respectively. Ultimate analysis of coals show that these coals are of low rank, high moisture, high volatile and of non-coking type. Calorific value of the coals ranged between 11410 and 12500 B.t.u./lb.

Production of semi-coke

Both washed and unwashed sized Orissa coals were carbonized at medium temperatures using the normal steam quenching process. The average throughputs were maintained between 7 and 9 tonnes per retort per day. The retort flue temperatures were kept 1010 – 1040°C. at the top and 850 – 900°C. at the bottom. One of the Orissa coal was also tested with CFRI gas quenching process at different throughputs ranging from 8–15 tonnes per retort per day.

Results and discussion

The yield of semi-cokes and by-products obtained on medium temperature carbonization are shown in Table 2. The yields of the products depend on coal throughputs, flue temperatures and other operating conditions besides the quality of coal used (washed or unwashed). The quantity of semi-coke produced per tonne of coal charged varied between 0.56 and 0.63 tonnes. The volatile matter and ash contents of the semi-cokes on as-received basis were found to range between 2–4 and 17–21 per cent respectively. The percentages of sulphur and phosphorus in the semi-cokes were 0.3–0.4 and 0.01–0.06 respectively. The results of various physical tests carried out on the semi-cokes indicate that these are highly suitable for industrial and domestic uses[4,5]. Results of the physical tests are given in Table 3. The + 1 in. shatter value of the semi-cokes were 68–78 per cent showing moderate resistance to degradation. The semi-cokes are also found to be highly reactive which may be a favourable feature for their use in large low shaft furnaces. The ignition points of semi-cokes were also quite satisfactory for use in domestic hearths. The semi-cokes were also suitable for industrial purposes from the point of view of their ash analysis and fusion characteristics.

From Tables 1 to 5 it can be seen that the yield of tar per tonne of coal carbonized is high (16–19 gal.) and their quality is also found to be quite good. These are characterized by low moisture, free flowing properties, high percentage of tar oils and high content of tar acids in the tar oils. The quantities of pitch residue obtained on simple distillation of these tars are relatively low.

The yields of gas produced per tonne of coal from these Orissa coals varied between 8,200 and 10,600 cu. ft. The average composition of the gas produced are shown in Table 4 along with their calorific values and densities. The data on gas production, consumption and surplus in therms are indicated in Table 5. The quality of semi-coke obtained by gas circulation of South Balanda coal was also found to be satisfactory and suitable for low shaft furnace. The yield of tar in this case is higher than that obtained by steam quenching process. Although the yield of gas decreases, its calorific value is higher than that produced by the conventional steam quenching process. Another point in favour is the considerable reduction in the yield of liquor.

Conclusion

Full scale medium temperature carbonization tests on both washed and unwashed Orissa coals show that these coals can be successfully processed in narrow continuous vertical retorts similar to those installed at the CFRI for the production of semi-coke suitable for low shaft furance and other metallurgical uses. The physical and chemical properties of the semi-cokes such as screen analysis, bulk density, shatter and micum values, calorific value, critical air blast values, ignition point, reactivity, etc., that these are ideal for use in low shaft furnance for pig iron production.

The semi-cokes produced from Talchir coals were tested, in the low shaft furnances of Industrial Development Corporation of Orissa and National Metallurgical Laborotary, Jamshedpur, and encouraging results have been obtained.

An additional advantage of carbonizing these Orissa coals is the high yield of good quality tar and sufficient quantity of surplus gas to the extent of about 40 per cent of the make gas which can be utilized for manufacture of fertilizers as well as for industrial and domestic heating[5]. In case the retorts are heated by producer gas or low shaft furnace gas, the entire quantity of oven gas will be available as surplus for further use.

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Conservation of Metallurgical Coal

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The most difficult task that the Coal Industry is facing today is how to meet the growing demand of metallurgical coal suitable for manufacture of hard coke of specified quality and strength.

Hard coke is one of the basic raw materials for a number of industries, the chief amongst which are the integrated Iron & Steel plants and foundry works. With increase in targets for production of iron and steel and consequent developments of the foundry industries, the demand for hard coke has considerably increased over the past several years and is likely to increase further in future Plan periods to keep up the tempo of industrial growth in the country.

Although India has been gifted with about 22,000 million tonnes of good quality iron ore, yet the quantity of metallurgical coal of usable quality is a small fraction (one-tenth) of the reserve of iron ore. Normally more than a ton of coking coal is required to produce one ton of pig iron. It is well known that indiscriminate mining and improper use in the past have resulted in substantial depletion of the reserves of our better quality coking coals. It is imperative, therefore, to adopt measures for effecting utmost economy in the use of this valuable raw material immediately in order to make it last till alternative methods suitable for extraction of iron without the use of hard coke are brought to perfection.

Coal seams and reserves of coal

The total reserve (proved, indicated and inferred) as estimated by the G.S.I. for all varieties of coal up to a depth of 610 meters (and in seams of thickness 1.2 m. and above) is of the order of 130,000 m. tonnes. Out of this about 4,000 m. tonnes of coal belong to the tertiary age and occur in the States of Assam and Jammu-Kashmir. The rest of the reserves are Gondwana coals occurring in peninsular India and deposited mainly along the valleys of rivers like Damodar, Mahanadi, Sone, Wardha Godavari and their tributaries. Coalfields like Raniganj, Jharia, Bokaro, Ramgarh, Karanpura, etc. are in the Damodar Valley. Coals occur in each coalfield in more than one horizon (called seams) the number of which may be as 20. The thickness of the seams in India may vary from a few centimeters to more than 100 meters. The physical and chemical properties of coals occurring in the different seams are often different.

Coking coals (that is coals which yield metallurgical coke on carbonization) mainly occur in seams X and above in the Jharia coalfield. The

largest reserves of medium coking coals, which are slightly inferior in coking property to the coking coals, are mostly found in the upper regions of the Damodar Valley in Bokaro and Ramgarh coalfields. Coals of the medium coking type also occur in the lower seams of the Jharia coalfield as well as in some parts of the Raniganj and Kanhan Valley coalfields. Coals still inferior to the above in coking property are conventionally known as semi-coking coals and are represented by the type of coal available in the Dishergarh seam of the Raniganj coalfield. The tertiary coals of Makum coalfield and South Khasi Hills in Assam also belong to this class.

The *in situ* reserves of the prime coking coal is about 6,100 m. tonnes against 8,300 m. tonnes of combined reserve of medium and semi-coking coals. Assuming 60 per cent recovery during mining of coal and 55 per cent recovery of clean coal after washing, the availability of coking coal will be of the order of 2000 m. tonnes. This reserve, though seemingly large, is only about 10 per cent of the iron ore reserve of the country. The requirement of coal as charged to the oven for the production of hard coke is closely tied up with the production of iron and steel. The targets for production of iron and steel by the end of Third and Fourth Plan periods are about 10 and 18 m. tonnes per annum respectively. Based on these figures the requirement of coal (as charged to the ovens) for the above periods are 12.7 and 25.3 m. tonnes respectively. This, however, includes washed coal which will be available at the time. The corresponding raw coal requirements will be 15.2 and 41.5 m. tonnes. These estimates are rather tentative and subject to alteration depending on changes in the production targets of iron and steel. The quantum of coal required for coking for the Fifth and subsequent Plans will evidently be substantially higher. In view of the growing demand for coking coals and its limited availability, planning must be made ahead for adoption of measures for its conservation both in production as well as in use.

The different means by which the supply of coking coal can be augmented and economy in its use can be effected are enumerated below:

(i) Upgrading of inferior coals by washing

(ii) Use of medium and semi-coking coals by blending with coking coals after proper preparation

(iii) Economy in the use of coke

Upgrading of inferior coals

Blast furnaces in operation in India have been designed for coke with about 22–23 per cent ash. Coke of this ash contents can only be produced if the ash in coal does not exceed 17 per cent. The level of ash in coal as produced now is on an average 24 per cent against 14–15 per cent in 1935.

Depletion of better qualities of coal over the past decades and adoption of mechanized methods of mining for augmenting production in future will cause still more deterioration in quality and by 1971 the ash level in the run-of-mine coal is expected to be 28 per cent. It will, therefore, be necessary to wash the whole production of coking, medium coking and semi-coking coals to bring down its ash to 17 per cent or below in order to maintain the stipulated ash in the coke[1,2].

Blending of coals

Though the upgrading of coal by washing will offer a solution to the increasing ash in raw coal, it will not substantially help to augment the availability of coking coal. Use of medium coking and semi-coking coals in blend with coking coals in substantial proportion will go a long way to help the cause of conservation of coking coal in use[3,4]. But blends containing these coals in very large proportions made the resultant coke weaker and unsuitable for blast furnance use. Optimum properties of the individual categories of coals making up a blend have, therefore, to be worked out by actual trials in coking plants. As the individual coals of the same category, i.e. coking, medium coking and semi-coking often differ in their coking properties, the proportions of the different coals worked out for a particular blend may not be suitable for another blend when the coals are different. The proportion for each set of component coals for a blend has, therefore, to be determined by actual tests in the coke ovens. For undertaking carbonization tests, use of large scale commercial plants is often difficult as :

(i) arrangement for separate crushing and blending may not be possible without disturbing the normal routine production

(ii) the test coals may not be available in sufficient quantity

(iii) variation of the carbonizing conditions and preparation techniques of the blend to find out the optimum conditions for getting best coke may not be possible, and a number of other reasons

A coal carbonization plant on a smaller scale in which provision for studies on carbonization under different conditions of preparation, heating and charging exist, should be employed for investigation. In the CFRI such a plant has been in operation since 1957. This pilot plant is a battery of three ovens having 350, 400 and 450 mm. widths and having separate flues, so that different temperature conditions can be maintained in each of them if desired. Sufficient coke is obtained from each charge for conducting physical and chemical tests for assessment of coke properties. Parallel tests in these and in commercial scale ovens have shown good correlation of the coke properties.

In selecting the component coals for a blend due care has to be taken to study their matching qualities. Exhaustive laboratory analysis is done on each coal followed by exploratory coking tests on small scale to find out its individual coking characteristics. The coals are then blended suitably and carbonized in the pilot coke oven plant and the coke obtained are tested for its physical and chemical properties. A number of trials are often necessary to determine the optimum proportions and most suitable conditions of carbonization.

Pilot plant studies

The CFRI has carried out numerous tests in the last decade as per its programme of investigations on the coking potentialities of different coals and their blends. Samples of these coals have been drawn either from the existing collieries or from new areas to be opened up in near future. The programme of investigation broadly covered the following :

(i) Classification of the existing sources of coal supply into different categories like prime coking, medium coking and semi-coking etc.

(ii) Studying the coking potentialities of coals from prospecting areas which have shown encouraging results on preliminary laboratory tests.

(iii) Finding out the optimum proportions of a multicomponent blends of coals which would give the best coke under a set of conditions.

(iv) Studying the possibility of conserving coking coal by using non-standard coals in the blend in high proportions adopting suitable preparation and charging techniques.

A brief discussion of the different techniques under study is given below.

Oil addition to the charge. For incorporation of higher proportions of medium and semi-coking coals in the blend, some or all of the components have to be finely crushed. The fine crushing of coal again decreases the packing density of charge in the oven adversely affecting the throughput and to some extent the quality of coke. It is, therefore, necessary to increase the bulk density of the charge. Addition of small quantity of coal-tar of petroleum oils of high boiling point to the blend brings about significant increase in the bulk density, and also helps to improve the yield and the quality of the gas[5,6]. Pilot plant studies indicate that the quality and quantity of oil to be added depend on the size consist of the charge and its moisture contents. The throughput per oven increases by about 5 per cent though no consistent improvement in the coke properties were observed.

Stamped charging. The conventional method of charging coal is through charging holes at the top of the oven. Recent researches carried out in France and Germany have shown that if the coal blend is stamped outside in a stamping box and the stamped cake is introduced into the oven, the physical properties of the coke improve appreciably. The degree of improvement is not the same for all coals. Generally speaking, blends, containing medium or semi-coking coals in fairly large proportions along with coking coals respond significantly to stamp charging[3,7].

Stamping of the charge brings the coal particles closer and helps better cementation of the particles in the plastic state and thereby yields a stronger coke. Highly plastic coals when carbonized singly may not need stamping but when a blend contains a component which shows poor plastic properties or is non-plastic, stamping produces a better coke than what would have been obtained if the charge were not stamped.

Experiments on stamping in the CFRI have shown that besides helping conservation of coking coal, this process improves the size and density of coke, produces better coherence of the coke particles, reduces fissuring and improves the through put of the oven. Blending of coke breeze oven up to 5 per cent has been made possible by this process. The effect of stamping may be seen from Table 1.

Selective preparation. Coal is constituted of a number of distinct petrographic entities, the percentage distribution of which varies widely from coal to coal. Further, coal contains mineral matter, co-deposited with coal in the early stage of formation, and the distribution of the mineral matter through the coal mass is also not uniform. Thus even the quality of supply of coal from a single source is likely to vary and, therefore, calls for thorough crushing and mixing of the coal if a uniform coke is to be obtained from it[1,8].

Table 1 — Physical properties of coke from top and stamped charging

Blend	Micum Index 40 mm.		Micum Index —10 mm.		Shatter Index 38 mm.		Stability test +25 mm.	
	Stamped	Top	Stamped	Top	Stamped	Top	Stamped	Top
A	82.4	73.6	10.2	19.4	94.9	88.3	53.9	36.3
B	78.7	71.4	12.3	18.2	93.0	90.8	54.6	43.7
C	76.7	70.7	11.9	18.4	92.1	90.6	57.3	48.6
D	78.5	76.6	7.6	11.7	92.3	92.2	60.3	57.6

Table 2 — Effect of fine crushing of coal on coke properties

Blend	Size	Micum Index		Shatter Index		Stability +25 mm.
		+40 mm.	—10 mm.	+38 mm.	+12.5 mm.	
A	85% through 6 mm.	73.3	17.2	91.6	96.2	47.5
A	100% through 6 mm.	75.3	14.1	91.1	97.3	53.7
A	100% through 3 mm.	78.5	13.2	91.7	97.3	53.0

The inert contituents of coal, i.e., mineral matter as well as some of the petrographic constituents, if present in coarser sizes, provide centres of weakness in the coke mass and adversely affect the overall properties of coke. It is, therefore, absolutely necessary to crush the charging coals finely, sometimes as fine as minus 1.5 mm. if a satisfactory product is to be obtained.

The different petrographic constituents of the coal have separate crushing characteristics. A single crushing operation reduces the bright-constituent of coal to a finer state than the dull or inert constituents though it is the latter that need finer crushing. It is necessary, therefore, to screen off the fines and re-crush the coarse coal over again to an even finer state if necessary. This process of finer crushing of the inert constituents is called selective crushing. In India at present the coke ovens charging coal is normally crushed to about 80 per cent through 3 mm. size or even coarser. The investigations in the pilot plant at CFRI, have shown that the same blend on finer or selective crushing gives much better coke. It also makes it possible to use increased proportions of inferior coking coals in the blend. Table 2 shows the effect of finer crushing of coal.

The improvement in Micum indices are noteworthy. As a result of all these studies it has been proved that 50-60 per cent of a blend can be constituted by medium and semi-coking coals for the conventional coking method. The proportion can still further be increased if stamped charging or selective preparation techniques are judiciously applied.

Economy in use of coke

Though the blending of inferior coals is a major step towards the conservation of coking coals, the various steps for economizing the use of coke in blast furnace will also play an important role in this respect. The ratio of sized coke to pig iron, and that of run-of-oven coke to sized coke over a number of years are given in Table 3.

Table 3 — Ratio of sized coke to pig iron and run-of-oven coke to sized coke

Year	Sized coke/pig iron	Run-of-oven coke/sized coke
1956–57	0.90	1.14
1957–58	0.91	1.15
1958–59	0.95	1.17
1959–60	0.96	1.19
1960–61	1.01	1.18
1961–62	1.00	1.17
1962–63	0.95	1.17

The consumption of coke per tonne of pig iron has increased steadily from 0.9 to 1.00 up to 1960–61 and in 1962–63 it has recorded a fall. This might be due to deterioration of coke quality on account of gradually diminishing supply of superior grades of coking coals.

Recent researches in the field of metallurgy have revealed that the consumption of coke per tonne of pig iron can be substantially reduced by adopting any or all of the following steps:

(1) Injection of coal fines in the blast furnace makes it possible to reduce the coke rate by 18–20 per cent. With hydrocarbon injections 20 to 25 per cent reduction of coke rate can be effected. The injection of hydrocarbon should present no difficulty as 1.5. m. tonne of naphtha is surplus in the country.

(2) Coke rate can be decreased by about 10–15 per cent by using self-fluxing sinter and gas as heating medium in the sinter strand.

(3) High top pressure and controlled humidity of blast can effect a saving of 5–10 per cent in coke consumption.

If the above measures are adopted the coke rate per tonne of pig iron may be brought down from 950 kg. per tonne to as low as 600 kg. per tonne as has been done in Japan.

Blast furnace operators have so long preferred + 38 mm. coke for making up the charge though it is possible by careful burdening to use coke even up to 20 mm. size. The ratio of + 38 mm. coke to run-of-oven coke is 1.17 whereas that of + 20 mm. coke to run-of-oven coke is 1.11. If the lower size coke is accepted a saving of 5 per cent in coke can be made.

Thus a net saving of about 40 per cent in coal consumption can be effected by adopting the measures enumerated above.

A lower ash in coke substantially reduces the coke rate and limestone consumption. The Government of India was, therefore, sometime past considering the possibility of imparting low ash coals from abroad. Researches carried out at CFRI during the past two years have shown that the low ash coals of the Makum coalfield in Assam are quite suited for the purpose. It is true, that these coals are often high in sulphur, but the sulphur in the thickest seam of the Makum field is comparatively low.

Introduction of even 10 per cent Assam coal in the blend reduces the ash in coke by about 1.7 per cent and by double the amount when 20 per cent Assam coal is used. The sulphur in coke, however, is increased

by 0.15 and 0.30 per cent respectively. A significant reduction in the coke rate may be possible if this slightly high sulphur coke is acceptable to the blast furnace operators.

Conclusion

Reserves of prime coking coal in India being meagre compared to the vast reserve of iron ore, every effort should be made for its conservation both in production and its use. Steps that are necessary in this regard are:

(a) Upgrading of inferior coals by washing.

(b) Blending of inferior qualities of coking coals and adoption of techniques like selective preparation, stamped charging, etc.

(c) Economizing the use of coke in blast furnace by fuel injection, use of self-fluxing sinter, high top pressure and controlled humidity of blast.

(d) Increasing the availability of coke by using coke size down to 20 mm.

(e) Use of medium temperature coke from poorly coking or non-coking coals in low shaft furnace for the production of iron.

Of these, the washing and blending of coals are now adopted in the country, but improved preparation techniques for blending of sub-standard coals are yet to be adopted. Adoption of measures for economizing the use of coke which is also being aimed at will go a long way in conserving our limited resources of prime coking coals.

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Ductile Iron Castings : Scope for Replacement of Steel Castings & Forgings

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This paper argues that the steel castings industry in India, which is greatly dependent on the import of carbon and graphite electrodes, should till the foreign exchange position improves or local manufacture commences, consider substitution with ductile iron (S.G. iron) castings. The paper further analyses the scope for these castings to bridge the gap between demand for high-duty castings and available supply. It points out that ductile iron castings can be produced without any additional investment to existing foundries and that dependence on foreign exchange for this industry can be substantially reduced.

Ductile iron is a grey iron with the principal difference that free graphite occurs as spheroids rather than as flakes. This gives ductile iron elongation and strength comparative to steel castings. It differs from malleable iron in that the spheroidal structure occurs in the as-cast condition and not on heat treatment.

Various types of iron-base castings like malleable iron, ductile iron and high-alloy iron castings can replace steel castings and forgings—in many cases to advantage. The primary reasons for supporting ductile iron manufactnre at this stage are that: (i) unlike the case of malleable iron, no expensive heat-treating facilities are necessary, (ii) unlike alloy cast irons there is no dependence on imported metals such as chromium, nickel, and (iii) unlike steel castings there is no absolute dependence on the electric arc furnace. Furthermore, ductile iron because of its mechanical and metallurgical properties can be cast into intricate shapes, thus substituting for forgings. Also hollow castings, like crankshafts can be readily made, permitting economy in metal.

The present installed capacity for steel castings is of the order of 280,000 tonnes. Even if 50 per cent of this capacity is to be utilized, it will require the import of electrodes to the extent of Rs 21 lakhs. The estimated Third Plan demand for steel castings is 200,000 tonnes. Thus, even if 50 per cent of the capacity of the industry is utilized, there will still be an unsatisfied demand for 60,000 tonnes. It is estimated that production of ductile iron to the extent of 50,000 tonnes per annum can easily be accomplished by the foundry industry in India and that it would replace an equivalent amount of steel castings and forgings.

The proportion of ductile iron castings to steel castings in the US in 1959 was about 20 per cent, i.e. about 200,000 tonnes. In 1964 over a million tons of ductile iron castings were produced. While the total steel

castings production in the US has not risen considerably since 1959, the proportionate growth of ductile iron has been phenomenal. In the US where materials are readily available and competition is keen, the production of ductile iron is about the same as that of malleable iron. In India, as shown in the estimates of NCAER (Table 1), ductile iron plays little or no part. This situation therefore needs to be remedied.

Recognizing that detailed statistics on the product-mix of foundry industry in India is relatively sparse it is difficult to accurately estimate replacement possibilty with ductile iron. However, from whatever figures on steel castings and forgings are available, pinpointing end-use application has been prepared (Table 2).

Almost any grey iron foundry can manufacture ductile iron. The basic-lined cupola is preferable. Quality castings can be obtained by using the duplex process where the basic melt is prepared in the cupola and metal conditioning and super-heating is done in a direct electric arc furnace. In the latter case since most of the heat required for the melting is obtained through coke usage, the dependence on graphite electrodes in the duplex operation is nominal.

However, to make ductile iron it is necessary to innoculate the melt with magnesium addition alloys. The magnesium content in ductile iron rarely exceeds 0.07 per cent. Hence import requirements of magnesium addition alloys are relatively small. Thus, for making 50,000 tonnes of ductile iron castings, the exchange equivalent will be Rs 3 to 4 lakhs.

The manufacture of ductile iron castings requires close control on the selection of raw materials. It also requires the development of satisfactory melting practices. At the same time it must be recognized that scope for ductile iron must really be measured by the willingness of the consuming industries to utilize them. Like all new materials there is always a hesitation to substitutes. However, examples can be drawn from all over the world to show the substitutability and versatility of ductile irons.

Table 1 — Iron castings

Type of iron castings	NCAER estimate* (in tonnes)		USA production (in tonnes)	
	1965-66	1970-71	1959	1960
Grey iron castings	1,175,600	1,825,300	12,329,170	11,592,460
Malleable iron castings†	37,900	71,800	916,360	8,20,700
White and chilled castings	9,200	18,500	n. a.	n. a.
High-alloy iron castings	3,900	10,100	n. a.	n. a.
Ductile or noduler iron	400	900	201,000	n. a.
Total	1,227,000	1,926,600		

*Excluding provision for stocks and exports

†Includes pipe fittings

Table 2 — Target and demand of steel castings and breakdown of components to be replaced by ductile iron

Industrial group	Total target (tonnes) 1970-71		Demand* (tonnes) 1970-71		Scope of replacement by ductile iron
	Steel	Forging	Steel	Forging	
	475,000	150,000			
Mech. Engng industries (Gr. I)			41,220	6,070	Replacement shown under
-do- (Gr. II)			—	7,200	Steel Mills
Industrial machinery			82,860	20,900	Cantilever head, bull gears, clamp cylinder for hydraulic presses, etc. —4,000 tonnes
Machine & small tools			210	1,020	Fixture pallet, fixture locking arm lever, links for chains, drag links, cross rail, etc. —1,000 tonnes
Internal combustion engines & allied industries			26,900	104,960	Connecting rods, crankshafts, fuel pump rockers hub & drum, axle equaliser beam, axle, housing, etc. —200,000 tonnes
Electrical engineering industries			8,930	6,450	
Mineral & oil industries			2,000	—	Valves, etc. — 1,000 tonnes
Maintenance			55,000	13,000	
Instruments			—	200	
Shipping, road transport, power irrigation, agriculture			50,000	65,000	Tractor driving flange, tractor output shaft, bottom flow, etc. — 8,000 tonnes
					Flywheel starter gears, engine cylinder, cylinder head, propellers —5,000 tonnes
Steel mills					Metal working rolls —15,000 tonnes
					Fitting on furnace lines, coke oven doors, ingot moulds, charging, boxes, sintering plant pellets, runout table rolls —10,000 tonnes

NOTE — Total replacement potential for steel castings = 64,000 tonnes

*Reappraisal of Steel Demand, Vol. 1, Sept., 1963, NCAER.

From the technical point of view ductile iron castings can be of more intricate nature than conventional grey iron castings. This enables ductile iron castings to substitute for forgings. In this case the economics of ductile iron manufacture should be considered against fresh investment in forge presses and the dependence of the latter on alloy steel dies.

Ductile iron castings can also be considered as replacements to high-duty non-ferrous alloy castings, such as aluminium bronze, etc. This is because many grades of ductile iron castings display almost the same range

of physical and metallurgical properties as non-ferrous castings. Furthermore, many grades of ductile iron castings are corrosion and oxidation resistant and in this sense are substitutes for more common grades of alloy steel and high-alloy castings.

In consequence, this paper argues that there is a real place for the ductile iron castings in the Indian economy. These castings will not only pave the way for reduced dependence on imported consumables but in a very real sense help to bridge the gap between demand for steel castings and forgings and their available supply. In no way are ductile iron castings, where applicable, inferior to steel castings and forgings. Foreign statistics on the relative usages of ductile iron, malleable iron and steel castings need have no essential bearing on Indian economy, since in these countries the apportionment is dependent on the relevant economics of production and application and not on import availability of raw materials. The estimated figures for ductile iron castings may well be on the low side where their full scope is closely examined. However, to bring about the greater use of ductile iron castings, various research laboratories and the industry should develop appropriate techniques for the manufacture and application of ductile iron.

Limits of Economizing Copper in Automobile Radiators

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The recent upward trend of world copper prices which touched a new hight during the Rodhesian crisis and the present difficulties in our foreign exchange balances has been causing considerable anxiety to the industries using copper and copper alloys. Furthermore, the importance of copper as a strategic metal in times of war has forced our government to take certain positive steps to ensure judicious utilization of the same. As a natural consequence, the electrical industries, a major user of copper have now switched over to aluminium on items where such substitution was feasible.

Table 1 shows the total quantity of copper imported into the country. Alongside is also shown the consumption of copper by the radiator industry.

The figures are based on estimates of original equipment requirements of the automobile industry. Defence vehicle and replacement needs have not been included. A close study of the consumption pattern would reveal that only around one per cent of the total imported material finds its way to the radiator industry. Even if we were able to achieve one hundred per cent substitution in the radiator industry, it will only have a negligible effect towards cutting down of imports. However, should we be forced by circumstances to proceed with the elimination of copper, a well tried out material, due attention will have to be paid to insure that there is no reduction either in the performance or in the life of the vehicle. Should this not be possible, it would be wiser to retain the use of copper to avoid the national loss that is likely to be caused by the premature scrapping of the vehicles.

Table 1 — Import of copper and consumption by the radiator industry

	1960	1961	1962	1963	1964
Import in wrought & unwrought form, metric tons	63,078	61,903	70,603	73,520	66,748
Value, millions of Rs	216.2	194	232.7	251.2	237.9
Quantity used by radiator industry, metric tons	577	588	637	623	767
Vehicle production	52,116	54,454	57,817	52,297	67,135
Percentage of total	0.92	0.93	0.90	0.86	1.15

NOTE—(1) Does not include ordnance factory production of defence vehicles

(2) Items used in radiator imported as unwrought or wrought brass have not been taken into account

We shall now explore the various possibilities and the areas where a saving or substitution of copper is feasible. The relevant problems arising out of such changes will also be discussed.

Reduction in material thickness

It is possible to effect reduction in metal thickness of the various components to the extent indicated, without causing a lowering of thermal efficiency:

(i) Fin copper strip 0.065 mm., (ii) Tube brass strip 0.14 mm., and (iii) Tank & tube plate brass sheet 0.60 mm.

The only adverse effect in reducing the thickness of stock is a reduction in the life of the radiator. This is mainly brought about by corrosion rather than premature structural failure. Control of corrosion is possible, if we resort to a sealed cooling system. However, the entire success of such a system will depend on the ability of the vehicle manufacturer to provide a wide network of maintenance facility throughout the country. The conditions prevailing today where roadside water is used for filling radiators does not appear to be very conducive for the introduction of a sealed engine cooling system.

Steel fins

Copper fins can be readily replaced by solder coated steel fins, without involving any change in the manufacturing process. To partially compensate for the lower thermal conductivity of steel, an increase of 20 – 30 per cent in the number of fins will be required.

In spite of the protective coating, steel fins do rust in due course, mainly because of exposure to hot and humid atmosphere. The rough rusted fin surface easily acts as a trap for dust and other foreign matter. In course of time the dirt built up on the fin surface will cause restriction to free air flow and heat transfer. A 50 per cent reduction in air flow will reduce heat dissipation by 38 per cent. Therefore, lowering of radiator performance cannot be tolerated in a tropical country like ours, where ambient temperatures are high.

In our estimate, the life of a steel fin radiator will not be very much in excess of 5 years, if fitted on a commercial vehicle. If this is so, two steel fin radiator replacements will be required in the place of a copper fin radiator, whose life has been firmly established to be over 10 years. A look at figures shows that to save 6.7 kg. of copper fins in a truck radiator, we will be wasting $2 \times 10.2 = 20.4$ kg. of copper in the form of brass tubes, tanks etc. not to mention valuable metal like tin in the solder. This point should be given serious consideration by people who advocate use of steel fins.

Complete substitution

Material used in the construction of radiators must possess the following properties: (i) Good thermal conductivity, (ii) Ease of forming into required shapes, (iii) Corrosion resistance to air and the liquid medium, (iv) Ease of joining by low temperature conventional soldering processes, and (v) Reasonable cost.

Table 1 shows thermal conductivity and specific gravity of copper, aluminium brass and iron.

Table 1 — Thermal conductivity and specific gravity

Material	Thermal conductivity C.G.S. units	Sp. gravity
Copper (Electrolytic)	0.92	8·96
Aluminium (E. C. Grade)	0.56	2.7
Brass 70/30	0.25	8.5
Iron	0.14	7.8

A cursory glance at Table 1 would show that aluminium is by far the most suitable substitute for copper for use in radiators. During periods of high price levels of copper, the radiator industry usually carries out a search for an alternate material. However, much headway was never made in this direction, mainly due to the drop in copper prices or because the required process changes were expensive.

In recent years the aluminium producers have put forward in the market low melting zinc solders and suitable fluxes. This should serve as a boost to the radiator industry to proceed with its own research programme to utilize aluminium. The current trend of high copper prices would definitely make such a possible change over, an economically attractive proposition. The main technical problem would be to improve the corrosion resistance of aluminium to the liquid coolant. We are sure that a solution to this will be found in the near future.

In conclusion, we may state that in case of an emergency, substitution to steel fins can be resorted to. However, it is to be noted that in the long run, such a step will only result in wastage of valuable materials due to the limited life of the radiator. The use of thinner material may be positive step to conserve copper, but the success of such a move will need the active cooperation of the vehicle owner. Lastly, among the various metals available for substitution, aluminium appears to be a logical choice. This is due to the high thermal conductivity and lightness of the metal, which are important considerations in the construction of radiators. Thus, if the world price of copper continues to remain at the present levels, large scale substitution of copper by aluminium will become an economic necessity in the radiator industry.

Economic, Industrial and Chemical Aspects of Detinning Industry

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Launching upon the crusade for the indigenous production of every imported item and their recovery from waste materials, beholds the future prosperity of the country. Metals fall in the queue of several items, whose import flings a heavy flow of country's wealth to the foreign countries and thus hangs heavily on the economics of the country. The country can ill-afford discarding the industrial wastes which could be reused as a secondary source of the metals. The tinned steel cans used for storing food products consume the largest proportion of the tin metal being imported to meet the country's requirements. Huge quantities of tin scrap which accumulate in the industry are a useful secondary source of tin and the detinned iron scraps of iron. Some data[1] regarding the tin plate and detinning industries are reviewed in Table 1.

Table 1 — Data regarding tinplate and detinning industries

	IMPORT & EXPORT	
TINPLATE		
(a) *Import*	Quantity (tonnes)	Value (Rs)
1961-62	44,529	42,837,052
1962-63	38,270	35,011,770
1963-64	49,650	46,875,114
(b) *Export*		
1962-63	1 ton	1,450
TIN SCRAP		
(a) *Import*		
1962-63	111	76,801
1963-64	707	4,02,755
(b) *Export*		
1963-64	507	69,168
1964 (April to Oct.)	648	—

Total tinplate consumption during 1963 is 1,40,000 tonnes.

Contd

Table 1 *Contd*

CURRENT ESTIMATES

Tinplate

(i) Estimated tinplate requirement during 1965–66	...	2·61 lakh tons
(ii) Estimated indigenous production of tinplates during 1965–66	...	1·40 lakh tons
(iii) Total existing capacity of tinplate plants	...	1·50 lakh tons

Tinplate scrap

(Nearly 10 per cent of the tinplates accumulate as waste scrap)

(i) Estimated availability of tin scraps during 1965–66	...	20,000 tons or more

Recoverable tin from scrap

(i) Estimate of recoverable tin metal from scraps during 1964–65	...	200 tons (average)
(ii) Import price of 200 tons tin	...	Rs 34 lakhs
(iii) Market price of 200 tons tin	...	Rs 60 lakhs

FUTURE ESTIMATES

(i) Estimated tin requirement during 1970–71	...	5,00,000 tons
(ii) Estimated availability of tin scraps during 1970–71	...	50,000 tons
(iii) Estimated availability of tin metal from scraps	...	500 tons
Import price of secondary tin		Rs 0·85 crore
Market price of secondary tin		Rs 1·50 crores

TINPLATE INDUSTRIES IN INDIA

Unit	Present capacity (tonnes)	Additional capacity licensed (tonnes)	present annual production (tonnes)
M/s Tin Plate Co., Jamshedpur	80,000	90,000 (expansion)	80,000
M/s Hindusthan Steel Ltd, Roorkela	50,000	150,000 (new line)	21,743
M/s Khemchand Rajkumar, Calcutta	20,000	60,000 (new electrotining line in Bombay)	12,000
M/s Satya Sheil Gupta, Kerala	...	10,000	......
	140,000	310,000	113,743

Firms to whom licences for detinning have been issued and recommended

Licence issued	Location	Capacity
M/s Metals Chemicals Works, Calcutta	Calcutta	49 tonnes per annum — double shift
M/S Monestone (P) Limited, Homjee Street, Fort, Bombay	Bombay	32.4 tonnes per annum in triple shift
M/s Detinners (P) Limited, 217, Chakla street Bombay	Bombay	35 tonnes per annum
	Total	116.4 tonnes

Licence recommended

M/s Hari Shanker, Canne Shanker, Kanpur

These data indicate the future scope of the detinning industry in the country. However, to have a precise information on the amount of tin which may be obtained from the secondary sources, some of the tinplate specifications have to be known in detail.

The statistics relating to tinplate specifications[2] will give information pertaining to the tinplate and detinning industries (Table 2).

Indian hot dipped tinplates contain 34, 40 or 45 g. of tin per sq. m. or say 18 to 20 oz. tin per basis box. The imported tinplates sometimes of electroplated type contain lesser percentage of tin metal. For reutilization of steel scraps the tin coating has to be removed from thc scraps before melting and thus impairs the properties of the steel. The maximum permissible amount being 0·05 per cent tin. The rcmoval of tin from tinplate scraps not only gives the high priced metal but enables processing and the reuse of steel scraps.

Table 2 — Tinplate specifications

Plate composition	Mild steel or low carbon content (0.04 to 0.12%) steel sheets quoted with commercially pure tin.
Thickness of steel sheet base	Normal thickness 0.01 in. (0.254 mm.) usual range 0.009 in. to 0.012 in. Other thicknesses available in the range of 0.004 in. to about 0.079 in.
Bases box	Consists of 112 sheets each of 20 x 14 in. size or lesser or larger number of sheets of equivalent area, i.e. 217.78 sq. ft (20.2325 sq. m.) or 62,720 sq. in. total surface (40.465 in. surface)
Weight of a bases box	0.011 in. (0.279 mm.) or B.G. 30.7 thick steel bases box weights 100 lb.
Weight and area relation of finished steel bases plates	41.82 lb. per sq. ft of 1 in. thick plate

TIN COATING SPECIFICATIONS

Hot dip tin coating

Coating thickness range	0.000015 to 0.0008 in.
Normal thickness	Less than 0.0001 in. (0.0025 mm.)
Tin coating thickness and weight relationship	0.0001 in. thick coating is equivalent to 0.0119 g. per sq. in or 1.72 g. per sq. ft or 18.5 g. per sq. m. or 0.0606or 1 lb.4 oz. per weight box

Electrolytic tin coating

$g./m.^2$	lb./base box	Tolerance (lb.)
5·6 to 11.2	0.25 to 0.5	0.03
16.8	0.75	0.05
22.4	1.00	0.07

TIN COATING RANGES BY WEIGHT PER BASE BOX

Hot dip tin coating range	0.85 to 2.3 lb. per base box
Electrolytic tin coating range	0.25 lb. to 1 lb. per base box
Ratio of the production of the electrolytic to hot dip tin plates in the world during 1955	65.35
Production of finished tin plates during 1955:	
World production	68 lakh tons
Production in India	0.7 lakh tons

Detinning processes

The earliest attempt in the direction of detinning of steel scraps seems to have been made by Higgins[3] as early as in 1854 in England. Chlorine gas was used for the removal of tin from the scraps. During the years 1876 to 1882 the electrolytic detinning process replaced the chlorine process. The discovery of the fact that completely anhydrous chlorine attacks the tin coating vigorously at temperatures even below 40°C.; chlorine process revived in 1907; a sophisticated method of using at low temperatures a solution of anhydrous chlorine in its solvents such as anhydrous stannic chloride or carbon tetrachloride was also advanced. Because of the ease with which large quantities of scraps could be handled in each single batch, these chlorine processes were acclaimed widely and practised till 1937 when the requirement of the product of this industry, viz. stannic chloride dwindled for the dyeing industry. Researches led in 1937 to the development of the alkali chemical process based on leaching of the scraps in alkaline sodium nitrate-nitrite solution. The alkali-chemical process replaced the earlier processes in several countries.

Most of the detinning processes[4,5] reported so far in the literature may be classified under the following categories: 1. Chlorine Processes. 2. Acid Chemical Processes. 3. Alkali Chemical Processes. 4. Alkali Electrolytic Processes. 5. Physical Processes.

Out of these five categories the Acid Chemical and Physical Processes are rather of historical importance only, since the commercial feasibility of none of the earlier processes could be established and none of the processes could be developed to a large plant scale. Some of the details and merits and demerits of these processes shall be briefly surveyed here. A successful new process developed by the authors of this article is also reported here.

Chlorine process

Chlorine readily reacts with tin to produce stannic chloride and evolve 127, 250 cal. of heat.

$$Sn + 2\,Cl_2 \rightarrow SnCl_4 + 127{,}270 \text{ cal.}$$

The important features of this reaction are that it occurs even in complete absence of moisture and secondly at pretty low temperatures (below 38°C.), contrary to the reaction of chlorine with iron for which moisture is essential while the low temperature is unfavourable. It has also been noted that ferric chloride which is obtained as the product of reaction between iron and chlorine accelerates the process of corrosion of iron while stannic chloride does not.

Higgins in England used as early as in 1854 chlorine gas for the removal of tin from the clippings. Later a number of patents on chlorine processes were taken in USA. Based on chlorine process a plant started operating in 1883 on Lake Zurich, Switzerland. The plant consisted of a reaction chamber in the form of a perforated false bottom iron cylinder of 3·96 meter height and 99 cm. diam. The chlorine gas was passed through the openings and the product of the reaction the stannic chloride was collected in a receiver kept under the cylinder.

In 1883 Lambottle in Brussels made use of shaft furnance as the reaction chamber. The chlorine gas strongly diluted with air passed through the bottom of the furnace filled with cuttings.

Goldschmidt who was pioneer in operating electrolytic detinning plant in Germany abandoned his earlier venture and adopted the chlorine process in 1907. Owing to this change over the chlorine process attracted greater attention in the later years. Goldschmidt process consisted of passing anhydrous chlorine gas under a pressure of 3·7 atmosphere at 0°C. or 7·6 atm. at 25°C. over completely dry tin scraps. Chlorine gas could penetrate all parts of the clippings owing to the high pressures. During the reaction between chlorinc and tin the gas pressure continues to fall and becomes constant when the reaction is over. The pressure reading was indicative of the completion of detinning process. Von Schutz passed diluted gas on the scraps by means of suction. Some complications were experienced with the clogging of the pipe lines. Murray and Fernbegger adopted the noble technique of dissolving chlorine in a solvent such as carbon tetrachloride and using the solution for the detinning purposes. Von Kugelen and Seward discovered and patented the fact that the temperature near the wall of the detinning chamber should be approximately 38°C. for efficient detinning.

Alkali chemical processes

Since the by-product stannic chloride obtained in chloride process has got limited application mainly in silk dyeing industry the latter could not find larger market before World War II and therefore the other processes gradually replaced chlorine process in several countries. The alkali process consisted in the following steps : (a) bringing in the scraps to the plant by means of railroad cars (b) removal of labels, lacquer and other organic matter from the scraps by heating in air at 425°C., (c) washing of the scraps, (d) detinning of the scraps in sodium hydroxide and saltpeter solution contained in cast iron drums, and (e) crystallising out sodium stannate by centrifugal process and lastly precipitating tin oxide by means of sodium carbonate.

In alkaline electrolytic detinning process[6], manganese dioxide, lead oxide (PbO), nitrous gases etc., have also been suggested as oxidizing agents. The electrolytic process of detinning consists in anodically dissolving out tin from the tin scraps in concentrated alkaline solutions at a temperature in between 50 and 90°C. The completion of the detinning is indicated by the oxygen gas evolution on the scraps. The tin scraps are carried by the conveyers in iron wire mesh baskets. The baskets are lowered in the iron tank which acts as cathode and carry the alkaline solution. The electrolyte is heated by means of hot air circulation around the electrolytic cells. After the completion of detinning the scraps are removed, washed and pressed in hydraulic press, the tin metal which deposits on the walls of the container as spongy tin removed periodically and then thoroughly washed, pressed and melted. The existing detinning industries in India at Bombay and Calcutta are adopting this electrolytic process.

The main disadvantage of alkali chemical and electrolytic process lies in using alkali in the process which is rather a costlier chemical and is to be partially imported. The electrolytic process has definite advantage of

Table 3 — Small scale 1 ton per day unit plan outlay

Capital investment : Break up	Rs
1. Rectifier 1000A./ 6 Volt	30,000.00
2. Tanks — 4 nos.	
3. Hydraulic press — 150 tons capacity	
4. Auxiliary equipments	
Recurring expenditure per day	
1 ton scrap	140.00
Hydrochloric acid (commercial) 400 litres	70.00
Organic inhibitor	25.00
Inorganic additional agent	70·00
Power consumption (60 units)	6·00
Graphite (0.1 kg.)	3.00
Labour charges	20.00
Transport	10.00
Building rent	10.00
Depreciation, Insurance, Bonus etc.,	15.00
Miscellaneous expenditure	10.00
TOTAL	379.00
Per day income	
Detinned scrap	150.00
Pure tin metal	360.00
Hydrochloric acid (reusable 100 litres)	17.00
Net profit per day	148.00
TOTAL	527.00
Summary	
Capital expenditure	30,000.00
Recurring expenditure per annum	1,13,700.00
Income per annum	1,58,100.00
Net profit per annum	44,400.00

higher efficiency at the same time the corrosion problems faced in the chlorine processes are less in these processes.

Miscellaneous chemical processes

A number of processes using sulphuric acid, hydrochloric acid, nitric acid, acid chlorides, acid sulphates have been found reported in the literature. In most of these processes an acid along with an oxidiser such as air, antimony oxide, sulphur dioxide, lead dioxide, chlorine gas, stannic chloride, ferric chloride, potassium iodate etc., have been used to detin the scraps. These processes are of rather historical importance. None of them could be commercialized because of the fact that either the basis metal iron was badly attacked in the process or the process was costly.

Acid process developed at CECRI

From the foregoing survey of the literature it may be noted that none of the commercial processes is making use of the cheapcst chemical like hydrochloric acid for the same reason that HCl readily attacks the basis metal iron and contaminates the tin liquor with excess of undesirable iron salt. Recently the authors[7,8] of this paper have succeeded in developing a cheap hydrochloric acid bath for detinning purposes making use of specific organic inhibitor, which inhibits the attack of iron base and at the same time accelerates the dissolution of tin metal when used in suitable proportion. Large number of experiments were carried out to cxplore most suitable conditions for efficient detinning in HCl-inhibitor bath. It was observed that the bath works efficiently in appreciably high concentrations of HCl and within a temp. range of 50 to 70°C. The mother liquor obtained in this process is further processed for the recovery of pure tin metal. Under ordinary conditions of electrolysis this mother liquor gives impure tin metal. On the addition of a specific inorganic reagent in quite a small amount, highly pure tin metal is obtained at the cathode during electrolysis. The tin deposit on the cathode in spongy form, which is latter melted to obtain ingots. Chemical analysis of the tin metal by the usual stannic oxide method gives a purity of 99·9. Nearly 1 per cent of the scrap is recovered as tin and 0·2 per cent of the iron is dissolved in the bath.

This new process can be adopted for large as well as small scale detinning industries. The financial aspects of a small scale plant of one ton per day capacity which can be set up without much machinery are given in Table 3.

Acknowledgement

Thanks are due to Prof. K. S. G. Doss, Director of this Institute for his kind interest in this work.

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Price: Rs 6.50 Sh. 13/- $ 2.00